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PASTURE STUDIES XIV

THE NUTRITIVE VALUE OF PASTURE HERBAGE

SOME PROBLEMS IN ITS ESTIMATION AND SOME RESULTS THUS
FAR OBTAINED AT MACDONALD COLLEGE.¹

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Studies which, by title or context, are taken as dealing with the nutritive value of pasture herbage may be assembled roughly into two groups according to whether chemical or biological methods form the basis of interpretation. The group in which chemical analysis alone forms the basis of the estimate of feeding value is by all odds the larger. Of this group, relatively few deal primarily with some fraction of the ash, particularly Ca and P. The remainder, for the most part, have involved the so-called "standard feeding stuffs analysis," or some part of it, as the criterion of nutritional value. Crude protein and crude fibre in particular have been depended upon as such indices.

Studies in which actual animal feeding has been involved include a number in which the "carrying capacity" of an area of pasture land in terms of animal units is the yard-stick used. In some few, the digestibility of the herbage, and usually of the fractions isolated by the usual feeding stuffs analysis, has been considered. The acceptance of the scheme of feeding stuffs analysis is, of course, implicit in such studies. A still smaller number have yielded data from which the feeding value of a measured quantity of herbage could be evaluated.

Obviously, unless these methods are closely correlated, there will be a different "nutritive value" for each method. The questions which immediately arise are: Which method gives the most useful picture? Are all pictures equally "in focus"? Ambiguous answers, regardless of method are, of course, undesirable. It is the purpose of this paper to examine in some detail certain methods which have commonly been used in connection with nutritional studies of pasture grass for the growth or fattening of animals, in order that the values and limitations of these methods may be better appreciated, and sound interpretations of the results of such projects be facilitated.

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THE FEEDING STUFFS ANALYSIS

Because of the extensive use made of the feeding stuffs analysis in nutritional studies, it may be well to begin this discussion with an examination of the biological significance of this scheme of describing pasture herbage. For some 40 years, feeding stuffs have been partitioned by a system of proximate analyses into five fractions, namely: nitrogen, ether extract, ash, crude fibre, and, by difference, nitrogen-free extract. On the basis that proteins contain approximately 16% nitrogen, the quantity of protein is obtained by multiplying the determined nitrogen by 6.25. The crude fibre is merely that fraction of the organic matter of the feed not soluble in successive dilute acid and dilute alkali treatments. It has been assumed, generally, that this residue is a biological unit representing the most poorly digested portion of the feed, while the nitrogen-free extract figure expresses, chiefly, the highly digestible carbohydrates.

These three fractions, protein, fibre and nitrogen-free extract, will be considered, particularly with reference to the extent to which they indicate feeding value of pasture herbage, as measured by the weight increases of animals subsisting thereon.

Crude Protein

From the large number of studies of the nutritional value of pasture herbage in which the effect of some treatment or condition on the protein content of the feed has been stressed, it is clear that it is quite generally believed that the protein level of the herbage is nutritionally significant. This, of course, is true in a broad sense. There may be some doubt, however, whether the increases in protein of the herbage which are frequently realized from nitrogen fertilization are necessarily nutritionally advantageous (2). Animals living entirely on untreated natural pasture herbage, typical of Eastern Canada, are consuming food of a higher protein level than they are offered on winter production rations. When supplementary grain-feeding to cows on pasture is necessary, low protein feeds are used, trials (15, 13, 8) having shown that it is energy rather than protein which is needed. Since protein is not stored in any appreciable measure in the animal body, there can be no argument that additional protein intake on pasture is advisable as a reserve against later need.

Carefully conducted studies during the past few years (11, 12, 14, 7), have amply demonstrated that, for most classes of stock, rations containing between 12 and 18% of crude protein are most efficient. By these standards, average pasture herbage cannot be considered as deficient in protein. It is, in fact, more probably deficient in total energy value.

It hardly need be noted that increased yield of herbage resulting from nitrogen application is quite another matter. The increase in percentage protein is largely the result of an increase in rate of plant growth, which means an increase in leafy parts—the high protein parts.

That crude protein may frequently be a misleading index to nutritive value, as measured by growth of rabbits, is evident from the following typical data (Table 1) from trials (5) at Macdonald College. The rations were the dried successive clippings of an area of sod land, the herbage of which was largely blue grass and red top.

TABLE 1.—TOTAL NITROGEN, CRUDE PROTEIN, DIGESTIBLE PROTEIN IN PASTURE HERBAGE CLIPPINGS AND THEIR NUTRITIVE VALUE FOR GROWTH

Date of clipping	Nitrogen, %	Crude protein, %	Digestibility of protein, %	Digestible crude protein, %	Gain 28 days (average of 10 rabbits per lot) gms.
May 12, 1936	4.1	25.6	63.7	16.3	214
June 3	4.5	28.1	70.2	19.7	230
June 20	3.9	24.4	59.8	14.6	173
July 9	3.8	23.8	59.9	14.2	104
July 24	3.8	23.8	62.2	14.8	205
Aug. 20	3.8	23.8	53.5	12.7	239
Sept. 10	4.4	27.5	66.0	18.2	260

Average daily air dry feed intake 117 grams with a standard deviation of 11%.

Neither the total crude protein nor the digestible protein calculated from digestibility coefficients obtained in this test are correlated with the gains in weight made by growing rabbits.

In another series of tests (3), natural mixed herbage, which when fed alone was not a maintenance diet, showed equal improvement in feeding value when fed at the same level but supplemented either with casein or with sucrose, as measured by rabbit gains (Table 2).

TABLE 2.—TWENTY-EGHT DAY GAINS OF RABBITS ON PASTURE HERBAGE

Item	Mixed pasture herbage	Herbage + 5% casein	Herbage + 5% sucrose
Gain (or loss)	-134 gms.	+30 gms.	+30 gms.
Crude protein	13.8%	18.0%	13.0%
Crude fibre	23.4	21.8	21.8
N-free extract	53.1	50.4	55.4

The pasture herbage in this case contained a noticeable quantity of rank-growing weeds, which probably accounted for the low feeding value. The point of importance at the moment, however, is that it was apparently energy and not protein which was the more marked dietary deficiency—and obviously, the protein figures did not correlate with feeding value.

Crude Fibre

This carbohydrate fraction has been used as an index of feeding value (or lack of it) with apparently little attention to its biological significance. Its use as an index lies in its supposed relation to the utilization, not only of this fraction itself, but of that of other nutrients. To the extent that such utilization is indicated by digestibility coefficients, however, the usefulness of the crude fibre of pasture herbage in this respect is by no means certain. For example, data reported by several workers (Table 3) fail to indicate any clear distinction between the utilization of crude fibre and that of nitrogen-free extract.

TABLE 3.—DIGESTIBILITY OF PASTURE HERBAGE BY SHEEP OR BY STEERS

Description	Dry matter, %	Organic matter, %	Ether extract, %	Crude protein, %	Carbohydrate		Reference
					Crude fibre, %	N-free extract, %	
Sheep—							
Dried clippings	74.3	77.2	51.8	76.7	74.5	81.4	Watson, S. J. (1)
Dried clippings		76.4	59.6	76.4	79.2	76.9	Watson, S. J. (2)
Dried + ground clippings		78.6	72.6	75.5	79.9	79.9	
Dried clippings	71.6	73.6	51.0	67.1	77.6	74.3	Watson, C. J. and Godden W. (3)
Grass silage	71.7	73.0	77.7	67.7	77.3	71.7	
Dried grass cake		78.1	70.6	78.2	78.3	79.3	Woodman H. E. (4)
Fresh grass 1925		78.7	54.1	80.6	78.5	80.5	
Fresh grass 1926		79.9	60.3	82.4	81.9	80.1	
Dried clippings	76.0		73.0	76.0	83.0	83.0	Hodgson, R. E. (5)
Steers—							
Reed canary grass	61.4		53.3	85.1	71.5	46.1	Garrigus, W. P. (6)
Brome grass	51.8		39.0	78.5	58.8	40.2	
Dried clippings	63.8	67.4	29.8	75.0	65.7	67.2	Crampton, E. W. and Campbell, J. A. (7)

(1) J. Agr. Sci., Vol. 21, p. 414–423, 1931.

(2) J. Agr. Sci., Vol. 21, p. 424–441, 1931.

(3) Emp. J. Exp. Agr., Vol. 3, p. 346–350, 1935.

(4) J. Agr. Sci., Vol. 20, p. 53–62, 1930.

(5) J. Agr. Research, Vol. 50, p. 147–164, 1935.

(6) Proc. Amer. Soc. An. Prod. 1935, p. 75.

(7) Pasture Studies, Macdonal College, 1937, unpublished.

In not a single instance is there ground for assuming that the partition of the carbohydrates of the feed into crude fibre and nitrogen-free extract isolates a fraction (crude fibre) of consistently lower digestibility and one of appreciably higher digestibility than any other organic constituent included in the feeding stuffs analysis, barring ether extract, which is frequently of very low digestibility in this type of feed. In fact, in many cases crude fibre is the most digestible fraction of pasture herbage. Obviously then, crude fibre is not a reliable index of low nutritive value in pasture studies.

If this situation is contrary to popular belief or usage, it is doubtless due to the assumption that animals utilize the fractions of pasture herbage in a manner analogous to their utilization of these fractions from such feeds as mature hays and cereal grains, or the several grain by-products. Some idea of the situation may be had by comparing the digestibility of the crude protein, crude fibre, and nitrogen-free extract of dry roughages and concentrates, calculated from data presented by Morrison² with that of pasture herbage from Table 3.

² Morrison, F. B., Feeds and Feeding, 1936.

TABLE 4.—AVERAGE DIGESTION COEFFICIENTS OF FEEDS BY RUMINANTS

Kind of feed	No. cases	Coefficient of digestibility		Percentage of cases with crude fibre as highly digested as N-free extract
		Crude fibre	N-free extract	
Dry roughage	110	52.4	59.5	39
Concentrates	88	53.3	78.5	10
Pasture herbage	12	75.5	71.4	67

Evidently crude fibre from mature plant material differs in feeding value from that of tender pasture herbage. The explanation of this difference may lie in the extent and/or nature of the lignification of the cellulose of the feed, as suggested by Woodman and Stewart (17, 18). Feeding trials at Macdonald College (5), have shown that increases in lignin in pasture clippings made shortly following a dry, hot period at the end of June (1936) may be correlated with lower digestibility of cellulose, and with decreased gains by rabbits fed on such diets. These data are summarized in Table 5.

TABLE 5.—EFFECT OF LIGNIN ON DIGESTIBILITY OF CELLULOSE AND OF DRY MATTER OF PASTURE HERBAGE

Date of clipping	28-day gain of rabbits, gms.	Percentage lignin of diets	Percentage digestibility		
			Crude protein	Cellulose	Dry matter
May 12	214	11.1	63.7	27.03	44
June 3	230	10.6	70.2	29.56	44
June 20	173	11.9	59.8	24.69	44
July 9	104	13.0	59.9	13.79	38
July 24	205	11.2	62.2	28.31	45
Aug. 20	239	11.5	53.5	26.67	44
Sept. 10	260	10.9	66.0	33.94	47

The foregoing discussion is not intended to discredit the usefulness of the standard feeding stuffs analysis or to belittle the rôle it has played in scientific feeding. It seems evident, however, that there are limitations to the nutritional significance which can legitimately be given certain of the fractions isolated by this scheme when applied to pasture herbage.

TRIALS INVOLVING ANIMAL FEEDING

A considerable number of so-called "grazing" trials are recorded in the literature relative to the nutritive value of pasture. From the practical standpoint, such trials yield much valuable information.

Grazing trials, however, do not permit a direct measurement of feed consumption by the animals. The nutritive value of the herbage then cannot be determined by such trials, unless some assumption is made con-

cerning feed intake or some indirect measurement of it is resorted to. Three methods have been used in attempts indirectly to measure the consumption of herbage by grazing animals, based respectively: (1) on clipping, (2) on gains in weight, and (3) on the use of a previously determined coefficient of digestibility of dry matter of the herbage. Each of these plans is subject to limitations.

The clipping method, in principle, assumes that if one of two plots of comparable area and ground cover is grazed, and subsequently both are clipped, the difference in the weight of the clippings will represent the quantity eaten by the grazing animal. For short-period studies and for comparisons between similar animals, this method is perhaps an advance on one with no record of food intake. The usefulness of this plan is, however, limited to small cultivated pasture plots, inasmuch as few natural pastures lend themselves to the requirement of comparable areas for grazing and mowing.

Recently, a proposal (1) was advanced to express yields of pastures in terms of nutrients, calculated on the premise that gains or losses in live weight bear a constant relation to the total digestible nutrient or the caloric value of the ration eaten. While for interpretation of the observed results under given conditions the plan may be useful, the problem of application, with different species of animals or even of animals of the same species but of different ages or sizes or degrees of fatness, involves assumptions the validity of which in any given case cannot easily be checked. For example, the change in the ration of a steer from an allowance of dry straw and hay to an unlimited quantity of pasture herbage not only alters digestive efficiency but may also change the body composition, particularly with respect to balance of water, fat and protein. The change in body weight may, then, for this reason alone be a misleading index of the quantity of dietary nutrients consumed.

Perhaps the most accurate plan for obtaining a record of intake is that proposed by Garrigus (9, 10), in which the consumption of a grazing steer is obtained from a record of the fecal dry matter excreted and the coefficient of digestibility of the dry matter of that herbage previously determined on clippings. The steers are fitted with feces collection sacks and allowed to graze at will. The feces sacks are emptied periodically and a record made of the dry material excreted. The dry matter consumed is then calculated by dividing the feces dry matter by the complement of the coefficient of digestibility of the herbage. In work with natural pasture herbage, a serious problem of obtaining a satisfactory sample for the digestibility trial is involved in this scheme. Changes in botanical composition or in the digestibility of the herbage with changing season would be complicating factors in studies of long enough feeding periods to measure growth or fattening.

Quite aside from the usefulness of his procedure in any given case, Garrigus' results with a number of steers indicate that freely grazing animals may be expected to show wide variability in their consumption of forage. That consumption is not closely related to size of steer is also evident from his data (Table 6).

TABLE 6.—WEIGHT OF ANIMAL AND DAILY DRY MATTER CONSUMPTION OF PASTURE HERBAGE BY FREELY GRAZING STEERS

Steer No.	Forage grazed	Weight of steers		Dry matter consumed	
		Individually	Average	Individually	Average
A	Blue grass, $\frac{1}{2}$ headed	938	963	25.8	19.5
	Alfalfa, $\frac{3}{4}$ bloom	988		13.1	
B	Clover mixture, $\frac{1}{4}$ bloom	535	535	12.3	12.3
C	Alfalfa, $\frac{3}{4}$ bloom	602	610	10.5	10.3
	Alfalfa, full bloom	618		10.2	
D	Alfalfa, $\frac{3}{4}$ bloom	758	766	12.0	12.0
	Alfalfa, full bloom	775		12.0	
E	Blue grass, 5 weeks	364	373	10.4	12.2
	Red clover, mature	362		12.3	
	Red clover, $\frac{1}{4}$ bloom	394		13.9	
F	Blue grass, 5 weeks	584	596	12.6	16.3
	Red clover, mature	582		19.7	
	Red clover, $\frac{1}{4}$ bloom	622		16.7	
G	Blue grass, 5 weeks	844	847	14.4	17.1
	Red clover, mature	834		19.5	
	Red clover, $\frac{1}{4}$ bloom	862		17.5	
H	Blue grass, 5 weeks	940	948	21.7	22.9
	Red clover, mature	942		25.0	
	Red clover, $\frac{1}{4}$ bloom	963		22.0	
I	Reed canary mixture	410	440	7.4	7.9
	Brome grass	470		8.5	
J	Reed canary	505	552	14.8	14.5
	Brome grass	600		14.3	
K	Reed canary	800	825	15.6	15.2
	Brome grass	850		14.9	
L	Reed canary	745	780	15.0	13.7
	Brome grass	815		12.5	

Garrigus states, "Analysis of the data fails to show any consistent effect of size of the steer on his rate of forage consumption. In as much as these steers were all healthy, moderately-fleshed Shorthorns differing mainly in weight, it appears that the variation in rates of consumption reflects merely the individual preferences, appetites and/or capacities of the steers."

Obviously, the feed consumption of a given animal must, over a long enough period, be correlated with body size and weight gain. The variation between steers, and even with different observations on the same steer, may easily be sufficient to make unreliable "animals units" based largely on size or age, as is seen in Figure 1.

Consideration of such evidence as has thus far been presented, which is but a fraction of that available, has led us to believe that for the ultimate solution of many of the problems relative to the nutritive value of pasture herbage, actual, controlled feeding tests must be used. The feeding stuffs analysis in its present form is a very uncertain index of nutritive value,

while grazing trials fail to yield the essential information concerning feed intake and thus do not differentiate between quality and quantity of feed. On the other hand, to carry out feeding trials with the larger farm animals is impracticable in cases where growth or fattening of the animal is considered. One need but note, for example, that for a digestion trial lasting only 30 days and involving only 4 steers, about one and one-half tons of air-dry herbage is required.

At least two lines of attack on this problem are obviously indicated. One is directed toward some modification in the scheme of proximate analysis for pasture herbage to make it more accurately descriptive of its feeding value; the other is a study of the possible use in the feeding tests of small pilot animals. During the past few years some attention has been given to both of these problems at Macdonald College.

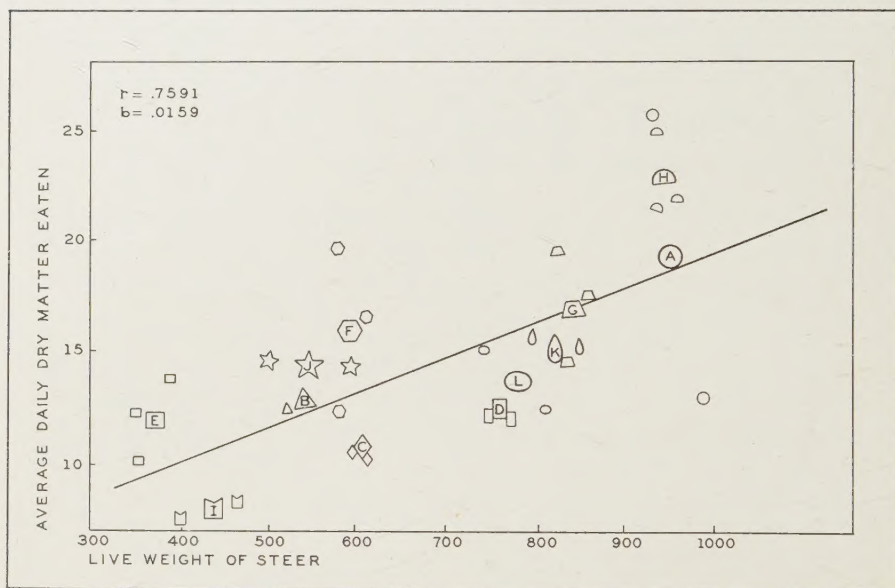


FIGURE 1. Correlation* Between Live Weight of Steer and Dry Matter Consumption when Grazing at Will.

*Correlation and regression calculated by the author from data from Garrigus. Values are based on averages of the several records of each steer. Letters indicate different steers.

MODIFIED SCHEME OF FEEDING-STUFFS ANALYSIS

In so far as the feeding-stuffs analysis is concerned, no detailed consideration of the work can be undertaken here. In brief, it may be said that one of the shortcomings of the present standard analysis is that the carbohydrate fractions isolated are neither biological nor chemical entities. They represent fractions of varying chemical makeup which are of unpredictable biological significance. As a possible improvement, it has been proposed (6) that the portion of the feed represented by the crude fibre plus nitrogen-free extract be partitioned into: (1) lignin, a very poorly utilized feed constituent; (2) cellulose, a chemical and biological unit the utilization of which by herbivora may be expected to vary inversely with the amount of lignin present; and (3) "other carbohydrate," a highly digestible mixture of hemicellulose, starches and sugars.

Application of the same scheme of analysis to feed eaten and to corresponding feces produced is the basis for calculation of the coefficients of apparent digestibility. The coefficients for rabbits obtained by the standard analysis plan and the scheme proposed are shown in Table 7. The data are taken from trials completed at Macdonald College (5) during 1937.

TABLE 7.—COEFFICIENTS OF APPARENT DIGESTIBILITY OF PASTURE HERBAGE BY RABBITS

Date of clipping	28-day gains of rabbits (1) gms.	Lignin in feed, %	Coefficients of digestibility (2)							
			Dry matter, %	Crude protein, %	Ether extract, %	Carbohydrate I		Carbohydrate II		
						Fibre, %	N-free extract, %	Lignin, %	Cellulose, %	Other carbo-hydrate, %
May 12	214	11.1	44	64	35	24	45	2	27	66
June 3	230	10.6	44	70	39	21	41	5	30	53
June 20	173	11.9	44	60	10	22	48	7	25	69
July 9	104	13.0	38	60	16	21	38	0	14	66
July 24	205	11.2	45	62	18	23	37	3	28	70
Aug. 20	239	11.5	44	53	18	21	53	—3	27	76
Sept. 10	260	10.9	47	66	30	13	56	12	34	68
Means	204	11.5	43.7	62.2	23.6	20.8	45.3	3.7	26.3	66.6
Standard deviation	(3)	0.8	2.7	5.3	11.0	3.9	7.1	6.1	6.2	6.9

(1) Growth data are averages of 10 rabbits per lot and represent gains in weight adjusted by regression to average feed intake and average initial weight of rabbit.

(2) For digestibility coefficients the total feed consumed and the total feces excreted by three rabbits of one lot were treated as a single observation for that lot.

(3) Standard error of gains for 70 rabbits = 76.3 grams. Necessary difference between means of lots of 10 = $\frac{s \times \sqrt{2} \times t}{\sqrt{n}}$ = 67 (where n = 10; s = 76.3; and $t_{p,05}$ for 69 degrees of freedom = 1.96).

The unexpectedly high, apparent digestibility of lignin from the September 10 clippings might lead one to question either the lignin values obtained or the record of feces excreted in this lot. Which of these possibilities is correct, however, cannot be ascertained since there is at present no chemical test for the accuracy of a lignin determination.

It may be noted in passing that the procedures for lignin determination, particularly in feeds where protein content complicates the problem, are not entirely satisfactory and require further study and refinement. Thus, while the principle of the proposed scheme of analysis appears to have certain advantages, biologically, in the study of the nutritive value of pasture herbage, the authors recognize the limitations of the present chemical methods for lignin, and present the scheme here more as indicating a new line of attack than as a finally proved plan. Study of this phase of the problem is being continued.

It is evident from Table 7 that the fibre-nitrogen-free extract partition does not follow the biological value of the herbage in so far as digestibility is correlated with growth. Also should be noted the sharp reduction in the digestibility of cellulose with the highest lignin content of the herbage and the poorest growth of the rabbits.

Subsequent to the completion of the above feeding tests, the herbage of May 12 and July 9 clippings was fed successively to a group of 6 rabbits, the results of which are summarized in Table 7a.

TABLE 7a.—COEFFICIENTS OF DIGESTIBILITY OF HERBAGE CLIPPINGS OF MAY 12 AND JULY 9

Item	May 12	July 9	Necessary difference for P = 0.05
Average gain 6 rabbits 10 days	35 gms.	—59 gms.	18 gms.
Percent digestibility of:			
Dry matter	45%	40%	2.3%
Protein	63	59	1.4
Ether extract	63	34	7.4
Crude fibre	31	21	3.8
N-free extract	39	40	2.6
Lignin	—7	—5	6.8
Cellulose	27	24	3.0
"Other carbohydrates"	68	72	5.7

This test substantiates the general findings shown in Table 7 to the effect that the midsummer grass is of lower feed value to rabbits than spring grass, and that the digestibility of dry matter, ether extract and cellulose is significantly lowered in the material of the higher lignin content.

USE OF RABBITS AS "PILOTS" FOR STEERS

In connection with the use of pilot animals in studies of the feeding value of pasture herbage, one of the first requirements is for information regarding the relative ability of the laboratory animal and the larger animal for which it is being substituted to digest the same type of diet. Comparisons between rabbits and steers in this respect have not been reported, and during 1937 trials designed to yield information on this point were begun at Macdonald College.

Table 8 gives digestibility coefficients from a test (4) in which pasture herbage, consisting of a composite of two season's clippings, constituted the entire rations of steers and rabbits.

TABLE 8.—COEFFICIENTS OF APPARENT DIGESTIBILITY OF DRIED PASTURE HERBAGE

Species	Dry matter, %	Crude protein, %	Ether extract, %	Carbohydrate I		Carbohydrate II		
				Crude fibre, %	N-free extract, %	Lignin, %	Cellulose, %	Other carbohydrate, %
Average 6 rabbits	45	65	19	24	45	18	33	62
Average 4 steers	64	75	30	66	67	34	68	92

The analysis of the herbage in the above test was:

Ash	9.5	N-free extract	41.4
Protein	27.5	Lignin	15.9
Ether extract	4.0	Cellulose	23.5
Fibre	17.6	Other carbohydrate	19.6

These data indicate that for steers as well as for rabbits, the proposed scheme of analysis for pasture herbage succeeds in partitioning the carbohydrate fraction, according to its biological value as measured by digestibility, more accurately than the present method.

The data of this table also reveal certain differences between rabbits and steers in their ability to utilize diets of pasture herbage. It is evident that the rabbits do not digest this type of diet as well as do steers in any constituent isolated by either method of chemical analysis. This, however, is not of particularly serious importance in the use of rabbits as pilot animals for steers, provided they behave relatively in a similar and/or constant way. This may be indicated by expressing the coefficients relative to the "dry matter" digestibility, thus removing the difference in "over all" digestibility. The recalculated values are given in Table 9.

TABLE 9.—DIGESTIBILITY OF FEED FRACTIONS RELATIVE TO THE DIGESTIBILITY OF DRY MATTER

Species	Crude protein	Ether extract	Carbohydrate I		Carbohydrate II		
			Fibre	N-free extract	Lignin	Cellulose	Carbohydrate
Rabbits	1.44	.42	.53	1.00	.40	.73	1.38
Steers	1.17	.47	1.03	1.05	.53	1.06	1.44

From these figures it is at once seen that, relatively, rabbits digest protein more thoroughly, and crude fibre and cellulose less completely than do steers. Lignin also appears to be slightly more broken down by steers than by rabbits. A possible explanation of this may lie in the long exposure to alkaline fluids in the rumen in the case of the steer. Since lignin in vitro is soluble in dilute alkali at ordinary temperatures, it would seem possible that conditions in the rumen might lead to its partial solution, thus permitting greater bacterial action on the cellulose than would occur in a non-ruminant herbivore such as the rabbit.

It is interesting that fats, nitrogen-free extract, and "other carbohydrates" are in relation to the dry matter digestibility equally well utilized by either species. "Other carbohydrate," containing the hemicellulose, starches, and sugars, is the consistently highly digested fraction of the carbohydrates. With steers, however, the nitrogen-free extract is not more digested than crude fibre, thus indicating again the questionable usefulness of this separation in nutrition studies of pasture herbage.

Data are not yet available to indicate whether the same differences, relatively, in digestibility and utilization of the same pasture herbage by steers and by rabbits will be maintained from one sample of grass to another. Studies are now in progress at Macdonald College designed to yield information on this point. The answer to this question will be of prime importance in determining the use which can be made of rabbits in digestibility studies of pasture herbage.

Rabbits and sheep do seem to show a rather striking constancy in this respect, as is evident from data reported in Table 10 by Watson and Horton (16.)

It is also interesting to note that rabbits show the same relative trend in their utilization of the feed fractions whether they be compared with sheep or steers. Rabbits unquestionably handle protein more completely and crude fibre less satisfactorily than do either sheep or steers.

TABLE 10.—DIGESTIBILITY OF FEED FRACTIONS BY SHEEP AND RABBITS RELATIVE TO THE RESPECTIVE DIGESTIBILITY OF THE DRY MATTER OF THE HERBAGE

Herbage	Species	Crude protein	Ether extract	Crude fibre	N-free extract
No. 1	Rabbits	1.25	.72	.74	1.06
	Sheep	1.04	.71	1.08	1.04
No. 2	Rabbits	1.22	.65	.80	1.06
	Sheep	1.06	.63	1.07	1.06
No. 3	Rabbits	1.22	.82	.81	1.03
	Sheep	1.06	.76	1.08	1.06

CONCLUSIONS

In conclusion, one might be justified in stating that the present status of the problem of the determination of the nutritive value of pasture herbage appears to be:

(1) That the complexity of the project is much greater than has been fully realized;

(2) That many of the criteria heretofore used are not only imperfect, but may be misleading indices of nutritive value of this type of food;

(3) That thus far the feeding value of pasture herbage can be established with certainty only by a feeding test; and

(4) That since it is impracticable to employ the larger farm animals in feeding tests in which growth or production of the animals is involved, further study of the possibilities of the usefulness of rabbits as pilot animals in such projects is justified.

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THE POLLINATION OF THE PEAR ON VANCOUVER ISLAND, BRITISH COLUMBIA

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INTRODUCTION

Pears, though normally healthy and full of bloom, in many instances fail to set fruit. There has been much evidence to indicate that this failure is due in many cases to a degree of self-sterility. Complaints of unfruitfulness in pears have been numerous from small gardens as well as from commercial orchards. After a number of unfruitful years, trees are either grafted over to another variety or removed outright. These studies on fruitfulness in pears began in 1929 and had as their object:—

1. The determination of the degree of self-fruitfulness in the 50 varieties grown at this Station;
2. The securing of information concerning the compatibility of commercial varieties in order to determine suitable varieties for interplanting to insure a reasonable set of fruit.

LITERATURE REVIEW

Self-incompatibility is an important factor in unfruitfulness of pears. Tufts and Philp (3) found in California that, while even self-fertile varieties could be expected to produce commercial crops without pollenizers, in no case did self-pollinations equal the normal set. Tufts (2) reports Bartlett self-sterile under valley conditions in California and only partially so in the foothills, with cross-pollinations greatly improving the set under both conditions. Anjou has been found to be self-sterile in the Hood River Valley (1) and satisfactorily pollinated by Bartlett. California workers (3) pointed out that self-incompatibility is not due to lack of pollen as little variation has been found in the amount of pollen produced by varieties under observation. All varieties produced an abundance. All investigators quoted agree that the honey bee is the chief agency through which fruit pollen is distributed.

BLOOMING DATES OF PEAR VARIETIES

If varieties are to cross-pollinate freely, there must be considerable overlapping of blooming periods. Records for a 10-year period (1921–1930) show that considerable overlapping does exist in blooming periods of most varieties, sufficient to insure a supply of viable pollen at the time the pistillate parts of the flower are ready to receive it. Weather conditions, at this time, influence the length of blooming period. In seasons where this period is short, the effect would be to limit the set of fruit. Unsatisfactory sets could be expected where very early and late blooming varieties were planted together.

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DOMINION EXPERIMENTAL STATION SAANICHTON, B.C. HORTICULTURAL DIVISION
 April AVERAGE BLOOMING DATE 1921 — 1930 May

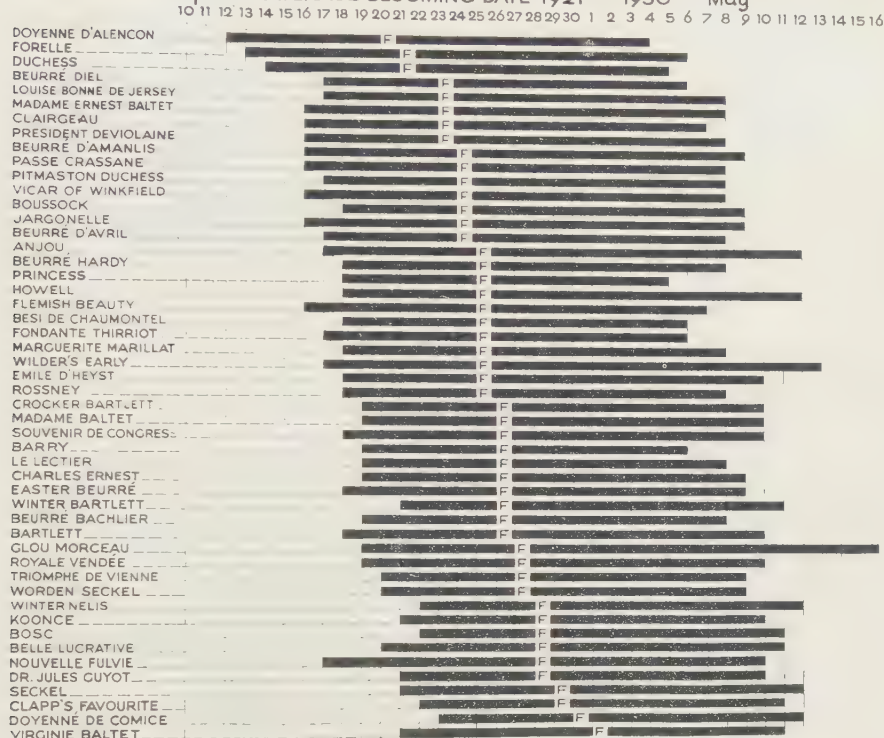


FIGURE 1

MATERIALS AND METHODS

Fifty-two varieties of pears have been grown in the orchards at the Dominion Experimental Station, Saanichton, B.C. Trees were planted in 1914, 20 feet $\times$ 25 feet apart. At time of planting, varieties were randomized with no thought of compatible varieties being placed side by side.

For the 5 seasons, 1929-33, selfing bags were installed in duplicate on all varieties and counts made of flowers and fruits set. It became apparent, as the work progressed, that a record of fruit maturing from bloom counts should be obtained. The amount of fruit set is important only in so far as a large proportion of it arrives at the stage of maturity. Since 1931, therefore, the data show counts of mature fruits resulting from flowers counted. In this way, the value of pollen, arising from any variety, upon its own flowers is determined.

A cotton bag fitted over a wire framework has been used throughout in these studies. The wire frame is approximately 10 inches in diameter and 16 inches long. When installed, the branch forms an axis passing lengthwise through the centre of the cage where it is held in position by means of free wire ends wrapped around the branch at either end of the cage. The branch selected should be reasonably straight, unforked, and may have to be cut back to a point where sufficient strength is obtained to

carry the weight of bag and cage. The cotton (unbleached, and of good grade) bag is pulled over the wire framework and tied in the usual way. This method of isolating flowers has been found to be most satisfactory, as the amount of interference of the bag with the bloom is reduced to an almost negligible quantity. Wire frameworks may be installed in early season before the fruit buds show colour. Later, just before the buds open, counts are made, bags pulled on and tagged.

Similar bags have been used as pollen-bags but in recent years paper bags have been found to be more suitable for this purpose. This is due partly because of ease of installation, and partly because frequently only a limited number of flower clusters are required.



FIGURE 2. View of cages installed throughout cherry orchard and used in pollination studies—similar cages used in pears.

Hand pollinations have been made in selfing-bags from 2 to 4 days apart. A cluster or two of flowers, taken from a pollen supply bag, has been found to make a very satisfactory brush for the purpose. By this method a thorough distribution of pollen is quickly made to the stigmatic surfaces with a minimum amount of injury to the delicate flower parts.

Results in the early years of the work indicated that many varieties could not be depended on to set fruit from their own pollen, and that the degree of self-compatibility was not sufficient to compare favourably with that of cross-compatibility. Consequently, cross-pollinations were made between many of the more important commercial varieties with the hope of finding suitable pollenizing varieties using Anjou, Bartlett, Bosc, Boussock, Conference, Hardy, Howell, and Louise bonne de Jersey. Emasculation has not been practised in order that labour might be reduced and more pollinations carried out than would otherwise be possible. Injury to the delicate flower parts from emasculation introduces another factor contributing to error. From blossom counts made in crossing bags, selfing-bags and on open branches on the same tree, and corresponding counts of fruit set and matured, comparisons are readily made.

The practice of collecting and storing pollen against the time when it would be needed has not been followed in these studies. Sufficient bloom is bagged before the blossoms open to given an abundance of pollen for the work required. Varieties as pollenizers can only be useful when supplying viable pollen at the moment it is required for transfer to the stigmas of the female parent. The first application of pollen is made when about 50–60% of the blossoms are open and the second application about the time the latest flowers are opening. This procedure brings the applications from two to four days apart.

Transfer of pollen has been satisfactorily effected by simply using flower clusters as a brush, direct to the flowers to be pollinated and in sufficient quantity to insure a supply of pollen to all stigmatic surfaces. The effectiveness of this method is shown by comparing results of sets and maturing fruit in controlled crossing tests with corresponding results under open (normal) crossing conditions. Bags are removed about the time petals fall and stigmas brown off.



FIGURE 3. Close-up of cage used in isolating bloom installed on cherry tree. Also 20 lb. paper bag for isolating bloom that is to be used as a source of pollen. Similar cages and bags used in pear pollination studies.



FIGURE 4. Cage for isolating bloom, installed on dormant branch for illustration purposes.

RESULTS

A.—SELF-COMPATIBILITY STUDIES

A marked degree of self-incompatibility exists in most pear varieties (Table 1). Only in Bachelier, Marguerite Marillat and President Deviolaine are sets from self-pollinations equal to or greater than sets resulting from open pollinations. Tested varieties are here classified according to their degree of self-compatibility, based on counts of bloom maturing into fruit.

Degree of Self-compatibility

Completely Sterile Varieties

Alencon, Anjou, Barry, Charles Ernest, Clapp Favourite, Comice, Crocker Bartlett, Diel, Easter Beurre, Koonce, Le Lectier, Madame Ballet, Passe Crassane, Pitmaston, Princess, Royale Vendee, Triomphe de Vienne, Virginie Baltet, Winter Nelis, Worden Seckel.

0.1-1.0 Per Cent Matured

Belle Lucrative, Bosc, Conference, Clairgeau, Glou Morceau, Hardy, Louise bonne de Jersey, Madame Ernest Baltet, Nouvelle Fulvie, Pulteney, Seckel, Souvenir, Winter Bartlett.

1.1-3.0 Per Cent Matured

Angouleme, Bartlett, Boussock, Chaumontel, Flemish Beauty, Howell, Jargonelle, Rossney, Vicar of Winkfield.

3.1-5.0 Per Cent Matured

Forelle, Marguerite Marillat, President Deviolaine.

5.1-10 Per Cent Matured

Avril, Bachelier, Dr. Jules Guyot, Emile d'Heyst.

10.0- Per Cent Matured

Amanlis, Fondante Thirriot.

TABLE 1.—PERCENTAGE SET AND FLOWERS MATURING FRUIT OF SELFED AND NORMALLY CROSSED FLOWERS OF DIFFERENT VARIETIES OF PEARS

Normal Set means fruit set under normal conditions when left open to insect pollination.

Variety	Flowers			Fruit matured			
	Years	Counted	Average set	Years	Flowers counted	Average set	Flowers maturing into fruit
	No.	No.	%	No.	No.	%	%
1. <i>Alencon</i>							
Normal Set	5	948	5.1	2	407	5.9	2.4
× Self	5	948	.3	2	407	—	—
2. <i>Amanlis</i>							
Normal Set	5	540	31.5	2	189	42.3	25.4
× Self	5	620	17.2	2	269	37.9	16.3
3. <i>Angouleme</i>							
Normal Set	5	967	5.4	2	358	4.1	2.5
× Self	5	827	3.3	2	218	8.7	1.8
4. <i>Anjou</i>							
Normal Set	9	2525	5.5	6	1818	6.0	1.4
× Self	9	1832	0.0	6	1125	—	—
5. <i>Avril</i>							
Normal Set	5	647	35.4	2	255	50.2	23.1
× Self	5	647	25.2	2	255	32.1	7.8
6. <i>Bachelier</i>							
Normal Set	5	838	19.8	2	445	16.6	4.2
× Self	5	748	13.6	2	355	18.3	5.1
7. <i>Barry</i>							
Normal Set	4	625	21.9	2	386	18.9	2.3
× Self	4	580	.3	2	341	—	—
8. <i>Bartlett</i>							
Normal Set	9	2115	20.3	6	1586	20.1	8.4
× Self	9	1464	4.7	6	935	3.6	2.0
9. <i>Belle Lucrative</i>							
Normal Set	5	837	24.8	2	355	20.5	10.1
X Self	5	837	4.9	2	355	6.2	.5

TABLE 1.—PERCENTAGE SET AND FLOWERS MATURING FRUIT OF SELFED AND NORMALLY CROSSED FLOWERS OF DIFFERENT VARIETIES OF PEARS—*Continued*

Normal Set means fruit set under normal conditions when left open to insect pollination.

Variety	Years	Flowers		Years	Fruit matured		
		Counted	Average set		Flowers counted	Average set	Flowers maturing into fruit
	No.	No.	%	No.	No.	%	%
10. <i>Bosc</i>							
Normal Set	7	984	37.7	4	580	30.0	8.4
× Self	8	927	7.6	4	523	9.1	.7
11. <i>Boussock</i>							
Normal Set	9	1444	14.7	6	1096	13.7	5.2
× Self	8	999	3.5	5	651	5.0	2.4
12. <i>Charles Ernest</i>							
Normal Set	5	686	17.7	2	285	14.7	3.1
× Self	5	677	2.8	2	276	—	—
13. <i>Chaumontel</i>							
Normal Set	5	706	36.8	2	274	47.4	10.9
× Self	5	707	9.7	2	275	18.9	1.4
14. <i>Clairgeau</i>							
Normal Set	8	1475	14.5	5	1177	15.2	4.6
× Self	8	877	3.1	5	579	4.6	.3
15. <i>Clapp Favourite</i>							
Normal Set	5	750	26.0	2	324	34.2	13.2
× Self	5	782	6.5	2	365	12.9	—
16. <i>Comice</i>							
Normal Set	5	1074	17.0	2	483	22.3	.2
× Self	5	1111	1.0	2	520	2.1	—
17. <i>Conference</i>							
Normal Set	5	993	33.5	4	856	36.9	7.8
× Self	5	601	16.1	4	509	17.2	.6
18. <i>Crocker Bartlett</i>							
Normal Set	5	505	28.5	2	253	26.1	9.5
× Self	5	476	.6	2	224	—	—
19. <i>Diel</i>							
Normal Set	5	740	18.6	2	333	19.5	7.5
× Self	5	740	0.0	2	333	—	—
20. <i>Dr. Jules Guyot</i>							
Normal Set	5	838	47.4	2	408	54.6	19.6
× Self	5	749	20.8	2	319	27.2	6.9
21. <i>Easter Beurre</i>							
Normal Set	5	737	6.9	2	341	6.4	3.8
× Self	5	731	1.2	2	335	.3	—
22. <i>Emile d'Heyst</i>							
Normal Set	5	670	34.9	2	285	40.0	28.1
× Self	5	672	5.3	2	287	9.4	7.3
23. <i>Flemish Beauty</i>							
Normal Set	5	609	27.9	2	244	28.7	7.0
× Self	5	620	5.8	2	255	9.4	1.5

TABLE 1.—PERCENTAGE SET AND FLOWERS MATURING FRUIT OF SELFED AND NORMALLY CROSSED FLOWERS OF DIFFERENT VARIETIES OF PEARS—*Continued*

Normal Set means fruit set under normal conditions when left open to insect pollination.

Variety	Years	Flowers		Years	Fruit matured		
		Counted	Average set		Flowers counted	Average set	Flowers maturing into fruit
	No.	No.	%	No.	No.	%	%
24. <i>Fondante Thirriot</i>							
Normal Set	5	753	23.7	2	307	28.0	18.2
× Self	5	752	8.1	2	306	17.6	10.8
25. <i>Forelle</i>							
Normal Set	5	796	28.5	2	294	50.3	11.8
× Self	5	788	2.5	2	286	6.3	4.2
26. <i>Glou Morceau</i>							
Normal Set	5	1348	20.2	2	654	14.0	.9
× Self	5	1187	1.7	2	493	3.6	.4
27. <i>Hardy</i>							
Normal Set	7	1206	19.4	4	658	21.1	3.6
× Self	7	1045	1.2	4	457	2.6	.2
28. <i>Howell</i>							
Normal Set	8	1646	18.7	5	859	25.5	8.0
× Self	8	1434	4.7	5	647	9.5	2.0
29. <i>Jargonelle</i>							
Normal Set	5	682	36.0	2	292	45.5	21.9
× Self	5	682	2.0	2	292	1.7	1.7
30. <i>Koonce</i>							
Normal Set	5	830	22.4	2	292	23.9	7.5
× Self	5	830	.2	2	292	—	—
31. <i>Le Lectier</i>							
Normal Set	5	985	5.6	2	284	4.9	1.7
× Self	5	991	0.1	2	290	—	—
32. <i>Louise bonne de Jersey</i>							
Normal Set	6	991	24.6	3	472	19.7	9.3
× Self	6	831	.6	3	312	1.6	.9
33. <i>Madame Ballet</i>							
Normal Set	5	1021	9.6	2	427	8.7	2.3
× Self	5	1176	0.0	2	582	—	—
34. <i>Madame Ernest Ballet</i>							
Normal Set	5	1496	24.1	2	713	28.0	7.0
× Self	5	1233	.4	2	450	1.1	.4
35. <i>Marguerite Marillat</i>							
Normal Set	5	590	33.5	2	284	28.5	8.1
× Self	5	550	21.1	2	244	34.0	3.7
36. <i>Nouvelle Fulvie</i>							
Normal Set	5	887	23.0	2	362	23.7	1.6
× Self	5	887	3.9	2	362	2.4	.3
37. <i>Passe Crassane</i>							
Normal Set	5	877	4.9	2	315	4.1	—
× Self	5	877	0.0	2	315	—	—

TABLE 1. PERCENTAGE SET AND FLOWERS MATURING FRUIT OF SELFED AND NORMALLY CROSSED FLOWERS OF DIFFERENT VARIETIES OF PEARS—*Concluded*

Normal Set means fruit set under normal conditions when left open to insect pollination.

Variety	Years	Flowers		Years	Fruit matured		
		Counted	Average set		Flowers counted	Average set	Flowers maturing into fruit
	No.	No.	%	No.	No.	%	%
38. <i>Pitmaston</i>							
Normal Set	4	600	13.0	1	187	9.0	2.1
× Self	4	600	0.0	1	187	—	—
39. <i>President Deviolaine</i>							
Normal Set	5	751	5.0	2	332	10.2	5.4
× Self	5	708	5.9	2	289	12.8	4.1
40. <i>Princess</i>							
Normal Set	5	1379	2.1	2	917	.9	1.8
× Self	5	1379	0.0	2	917	—	—
41. <i>Pulteney</i>							
Normal Set	4	686	12.9	3	561	10.3	5.1
× Self	4	579	1.0	3	454	1.1	.6
42. <i>Rossney</i>							
Normal Set	5	551	46.6	2	209	50.0	15.8
× Self	5	412	15.7	2	170	14.7	2.9
43. <i>Royale Vendee</i>							
Normal Set	5	772	25.4	2	308	24.3	6.1
× Self	5	764	.8	2	300	.3	—
44. <i>Seckel</i>							
Normal Set	5	398	38.0	2	105	46.6	3.8
× Self	5	495	6.0	2	202	11.3	1.0
45. <i>Souvenir</i>							
Normal Set	7	685	20.0	4	321	19.6	9.3
× Self	6	668	4.3	3	304	6.9	.6
46. <i>Triomphe de Vienne</i>							
Normal Set	5	694	12.6	2	301	6.0	5.3
× Self	5	645	0.0	2	252	—	—
47. <i>Vicar of Winkfield</i>							
Normal Set	5	628	30.5	2	244	31.6	11.4
× Self	5	628	.4	2	244	1.2	1.2
48. <i>Virginie Baltet</i>							
Normal Set	5	911	21.0	2	450	18.2	1.3
× Self	5	813	0.0	2	352	—	—
49. <i>Wilder Early</i>							
Normal Set	3	319	24.1	—	—	—	—
× Self	3	319	9.9	—	—	—	—
50. <i>Winter Bartlett</i>							
Normal Set	5	965	28.6	2	411	32.8	2.6
× Self	5	965	4.7	2	411	5.6	.7
51. <i>Winter Nelis</i>							
Normal Set	5	1316	4.0	2	604	1.8	.8
× Self	5	1299	0.0	2	587	—	—
52. <i>Worden Seckel</i>							
Normal Set	5	660	15.0	2	231	15.5	10.8
× Self	5	645	.1	2	216	—	—

Self-pollinations in all varieties gave an average set of 4.0%. This is for the entire period of testing as shown in the first column of Table 1. Cross-pollinations under "normal", open-crossing conditions increased the set from 4.0% to 19.5%.

TABLE 2.—AVERAGE SET OF NORMAL AND SELFED BLOOMS OF ALL VARIETIES TESTED FROM 1929 TO 1937

All varieties	Flowers		
	Counted	Set	Percentage Set
Normal	47782	9348	19.5
Self	43404	1742	4.0

Sets shown in Table 3 correspond closely to those in Table 2 but the periods covered by the two tables do not coincide. The number of flowers actually developing into mature fruit is very low. Causes for flowers failing to set, and for fruit failing to go on to maturity after having become partly developed, are

outside the scope of this article. Comparing set with matured fruit, considerable "June drop" is recorded and is greater in the case of self-pollinated flowers than in those cross-pollinated.

TABLE 3.—AVERAGE PERCENTAGE SET AND OF SET MATURING FRUIT 1932-1937

All varieties	Flowers			Percentage of set maturing fruit
	Counted	Percentage set	Percentage matured	
Normal	24132	20.0	6.4	32.2
Self	19949	5.8	1.4	25.0

B.—CROSS-COMPATIBILITY STUDIES

Tables 1, 2 and 3 show that cross-pollinations, under "normal" conditions, have consistently given greater sets of fruit and a greater amount of matured fruit than self-pollinations. Effective pollenizing varieties have been determined for many commonly grown varieties (Tables 4 to 12). In these tables are to be found the number of years of work on which conclusions are based, along with percentage of flowers set and percentage of flowers developing into matured fruit.

Reciprocal crosses have not been carried out in all instances but there is much evidence in the accompanying tables to show that the reverse cross conforms closely in effectiveness. An instance of high inter-compatibility is found in Bartlett and Howell and of low inter-compatibility in Anjou and Boussock.

Anjou is not only self-incompatible but finds difficulty in setting fruit under open crossing conditions. The "normal" set of 5.5% is much below the average for all varieties of 19.5%. Clairgeau pollen has given the greatest set in Table 4, with Conference being almost as effective. These two varieties have each given a higher percentage of flower maturing fruit than was obtained under "normal" conditions.

TABLE 4.—EFFECT OF DIFFERENT VARIETIES OF PEARS AS POLLENIZERS FOR ANJOU

Variety	Years	Flowers		Years	Fruit matured		
		Counted	Average set		Flowers counted	Average set	Flowers maturing into fruit
	No.	No.	%	No.	No.	%	%
<i>Anjou</i>							
Normal Set	9	2525	5.5	6	1818	6.0	1.4
× Self	9	1832	0.0	6	1125	0.0	0.0
× Bartlett	7	1139	3.9	5	959	4.2	.6
× Bosc	7	1106	4.8	5	941	3.8	.8
× Boussock	2	483	.2	2	483	.2	.2
× Clairgeau	6	904	7.7	5	811	6.4	2.2
× Conference	2	413	5.3	2	413	5.3	1.9
× Dr. Jules Guyot	5	603	3.8	3	364	5.2	0.0
× Howell	2	457	2.4	2	457	2.4	1.3
× Winter Nelis	3	508	4.7	3	508	4.7	.7

Bartlett exhibits a degree of self-compatibility, slightly above the average for all varieties (Table 5). Howell and conference have given sets equal to or greater than were obtained under "normal" conditions and have every indication of being satisfactory pollenizers for Bartlett.

TABLE 5.—EFFECT OF DIFFERENT VARIETIES OF PEARS AS POLLENIZERS FOR BARTLETT

Variety	Years	Flowers		Years	Fruit matured		
		Counted	Average set		Flowers counted	Average set	Flowers maturing into fruit
	No.	No.	%	No.	No.	%	%
<i>Bartlett</i>							
Normal Set	9	2115	20.3	6	1568	20.1	8.4
× Self	9	1464	4.7	6	935	3.6	2.0
× Anjou	6	495	10.5	5	428	10.7	5.3
× Bosc	2	338	8.0	2	338	8.0	2.3
× Boussock	2	298	.0	2	298	.0	.0
× Clairgeau	2	336	10.1	2	336	10.1	5.3
× Comice	2	538	13.0	2	538	13.0	2.9
× Conference	2	387	20.6	2	387	20.6	10.3
× Howell	3	372	25.3	3	372	25.3	11.8
× Louise bonne de Jersey	2	270	1.4	2	270	1.5	.4
× Souvenir	2	308	3.9	2	308	3.8	3.2

Percentage of set from self-pollinated flowers in Bosc is considerably above the average but the amount of fruit maturing from self-pollinated flowers is very low and marks Bosc as being almost self-incompatible. Bartlett is the best pollenizer for Bosc (Table 6).

TABLE 6.—EFFECT OF DIFFERENT VARIETIES OF PEARS AS POLLENIZERS FOR BOSC

Varieties	Years	Flowers		Years	Fruit matured		
		Counted	Average set		Flowers counted	Average set	Flowers maturing into fruit
	No.	No.	%	No.	No.	%	%
<i>Bosc</i>							
Normal Set	7	984	37.7	4	580	30.0	8.4
× Self	8	927	7.6	4	523	9.1	.7
× Anjou	3	281	7.4	3	281	7.4	3.5
× Bartlett	3	310	20.8	3	310	20.8	10.3
× Boussock	2	153	.0	2	153	.0	.0
× Clairgeau	2	158	4.4	2	158	4.4	1.2

Bartlett pollen is considerably more effective on Boussock in increasing percentage of flowers maturing fruit than "normal" pollen (Table 7).

TABLE 7.—EFFECT OF DIFFERENT VARIETIES OF PEARS AS POLLENIZERS FOR BOUSSOCK

Variety	Years	Flowers		Years	Fruit matured		
		Counted	Average set		Flowers counted	Average set	Flowers maturing into fruit
	No.	No.	%	No.	No.	%	%
<i>Boussock</i>							
Normal Set	9	1444	14.7	6	1096	13.7	5.2
× Self	8	999	3.5	5	651	5.0	2.4
× Anjou	2	205	5.3	2	205	5.3	1.4
× Bartlett	7	568	13.5	5	448	16.9	9.8
× Bosc	7	535	4.5	5	444	4.7	3.8
× Dr. Jules Guyot	5	220	11.8	4	217	11.8	3.1

Clairgeau self-pollinations have given a very low percentage of bloom maturing fruit (Table 8). Neither Bartlett nor Bosc are satisfactory pollenizers for Clairgeau.

TABLE 8.—EFFECT OF DIFFERENT VARIETIES OF PEARS AS POLLENIZERS FOR CLAIRGEAU

Variety	Years	Flowers		Years	Fruit matured		
		Counted	Average set		Flowers counted	Average set	Flowers maturing into fruit
	No.	No.	%	No.	No.	%	%
<i>Clairgeau</i>							
Normal Set	8	1475	14.5	5	1177	15.2	4.6
× Self	8	877	3.1	5	579	4.6	.3
× Bartlett	6	555	4.1	5	513	4.4	2.9
× Bosc	6	522	5.3	5	486	5.7	1.6

Table 9 shows that the percentage of set from self-pollinations has been sufficient, under ordinary circumstances, to result in at least an average crop. However, the amount of set maturing fruit is low indicating a very heavy "drop". Both Anjou and Bartlett have shown themselves to be satisfactory pollenizers for Conference.

TABLE 9.—EFFECT OF DIFFERENT VARIETIES OF PEARS AS POLLENIZERS FOR CONFERENCE

Variety	Years	Flowers		Years	Fruit matured		
		Counted	Average set		Flowers counted	Average set	Flowers maturing into fruit
	No.	No.	%	No.	No.	%	%
<i>Conference</i>							
Normal Set	5	993	33.5	4	856	36.9	7.8
× Self	5	601	16.1	4	509	17.2	.6
× Anjou	2	214	34.1	2	214	34.1	10.3
× Bartlett	3	365	34.8	3	365	34.8	6.3

Anjou, Bartlett and Howell pollens on Hardy have given relatively high percentages of bloom maturing fruit (Table 10). Each of these varieties, as male parents, gave a higher percentage of bloom maturing fruit than was obtained from "normal" pollinations.

TABLE 10.—EFFECT OF DIFFERENT VARIETIES OF PEARS AS POLLENIZERS FOR HARDY

Variety	Years	Flowers		Years	Fruit matured		
		Counted	Average set		Flowers counted	Average set	Flowers maturing into fruit
	No.	No.	%	No.	No.	%	%
<i>Hardy</i>							
Normal set	7	1206	19.4	4	658	21.1	3.6
× Self	7	1045	1.2	4	497	2.6	.2
× Anjou	2	314	9.8	2	314	9.8	5.1
× Bartlett	2	332	14.1	2	332	14.1	6.3
× Howell	2	293	15.7	2	293	15.7	4.1

In Table 11, while the percentage of bloom maturing fruit from "normal" pollinations is higher than those from Anjou, Bartlett or Hardy pollen, yet these three pollens have given a sufficient percentage of bloom maturing fruit to mark them as effective pollenizers for Howell.

TABLE 11.—EFFECT OF DIFFERENT VARIETIES OF PEARS AS POLLENIZERS FOR HOWELL

Variety	Years	Flowers		Years	Fruit matured		
		Counted	Average set		Flowers counted	Average set	Flowers maturing into fruit
	No.	No.	%	No.	No.	%	%
<i>Howell</i>							
Normal Set	8	1646	18.7	5	859	25.5	8.0
× Self	8	1434	4.7	5	647	9.5	2.0
× Anjou	3	513	5.2	3	513	5.2	4.9
× Bartlett	3	368	7.8	3	368	7.8	6.2
× Hardy	3	378	5.4	3	275	5.4	4.3

Bosc and Dr. Jules Guyot are marked in Table 12 as effective pollenizers for Louise bonne de Jersey. Bartlett and Louise bonne de Jersey are shown to be incompatible to a marked degree.

TABLE 12.—EFFECT OF DIFFERENT VARIETIES OF PEARS AS POLLENIZERS FOR LOUISE BONNE DE JERSEY

Variety	Years	Flowers		Years	Fruit matured		
		Counted	Average set		Flowers counted	Average set	Flowers maturing into fruit
	No.	No.	%	No.	No.	%	%
<i>Louise bonne de Jersey</i>							
Normal Set	6	991	24.6	3	472	19.7	9.3
× Self	6	831	.6	3	312	1.6	.9
× Bartlett	5	489	1.8	3	360	2.2	.3
× Bosc	5	431	20.1	3	279	31.5	7.5
× Dr. Jules Guyot	5	409	12.4	3	295	17.2	5.4

SUMMARY

1. A marked degree of self-incompatibility was shown in most pear varieties. Of the 52 varieties tested, 20 failed to mature fruit from self-pollinations.
2. Cross-pollinations under uncontrolled open-crossing conditions gave an average set of 19.5%. Self-pollinations gave an average set of 4.0%.
3. There was a greater “June drop” in fruits resulting from self-pollinations than in fruits resulting from cross-pollinations. The “June drop” from open cross-pollinations amounted to approximately two-thirds of the set.
4. Summary showing relative pollenizing value of various pear varieties tested and found effective.—

Female parent	—	Pollenizing variety		
		1st	2nd	3rd
Anjou	(Table 4)	Clairgeau	Conference	Howell
Bartlett	(Table 5)	Howell	Conference	Anjou, Clairgeau
Bosc	(Table 6)	Bartlett		
Boussock	(Table 7)	Bartlett	Bosc	
Clairgeau	(Table 8)			
Conference	(Table 9)	Anjou	Bartlett	
Hardy	(Table 10)	Bartlett	Anjou	Howell
Howell	(Table 11)	Bartlett	Anjou	Hardy
Louise bonne de Jersey	(Table 12)	Bosc	Dr. Jules Guyot	

5. Bartlett is an effective pollenizer for many varieties.
6. Except between earliest and latest varieties of pears to bloom sufficient overlapping in blooming periods occurs to provide a supply of pollen while stigmatic surfaces are receptive.

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SOME MORPHOLOGICAL CHARACTERS OF HELIANTHUS ANNUS L., AND THEIR RELATIONSHIP TO THE YIELD OF SEED AND OIL¹

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Sunflower seed contains an extremely high percentage of vegetable oil which is used extensively in the manufacture of various food products. After the oil has been extracted, the remainder of the seed is utilized as a cattle feed and for this purpose is comparable with linseed cake both in nutritive value and in palatability. Unfortunately, no statistics are available to show the amount of sunflower oil which is annually imported into Canada, but it is significant that, according to Sievers (17) the United States imported 27 million pounds of this commodity from Soviet Russia in 1931.

Climatic conditions in Western Canada are very similar to certain large areas in Russia where sunflowers are a staple and extensively grown crop. Mennonite farmers in certain sections of the Canadian West, notably in Rosthern and Morden districts, have been growing this crop successfully for many years and have demonstrated that good seed yields can be obtained consistently in these areas. It is therefore only logical that the possibilities of sunflowers as a field crop for the Prairie Provinces should be thoroughly investigated.

Russian plant breeders have originated several varieties of sunflowers each of which is specially adapted to a particular climatic zone. In Canada no variety for seed production has so far been evolved and little is known as to what type of plant should be selected for this purpose. The object of the experiment described in this paper is to show whether or not certain morphological characters are indicative of high yields of either seed or oil.

REVIEW OF LITERATURE

The review of literature herewith presented does not include any of the numerous articles relating to sunflower silage, but only those contributions which might prove of assistance to one engaged in breeding sunflowers for seed production.

Cardon (3) selected different types within the variety Mammoth Russian and tried to isolate these by the method of inbreeding. It was found that when the heads were covered with selfing bags all the flowers in each head opened simultaneously instead of in zones from the periphery to the centre as is normally the case. When harvested the self-fertilized heads looked perfect, but although the seed appeared to be plump, normally coloured, and apparently well-formed, no kernels were present. From these results it was concluded that it was not possible to inbreed sunflowers.

¹ Contribution from the Division of Forage Plants, Central Experimental Farm, Ottawa. Summary of a thesis submitted to the Graduate Council, Michigan State College in partial fulfilment of the requirements for the degree of M.S.

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An entirely different result was obtained by McRostie (12) who found that sunflowers were not totally self sterile. Like Cardon, he isolated the heads with a material which would prevent wind pollination. By this method of inbreeding he was able to produce uniform pure line strains of many different types.

Hamilton (10) also reported that in 1920 several hundred sunflower heads were selfed by covering them with Manila bags. These selfed heads yielded from 15 to 50% of the normal amount of seed and even better results were obtained in instances where the heads had been agitated.

As is the case with corn, inbreeding sunflowers for three generations resulted in a marked increase in the uniformity of the strains concerned, and a corresponding decrease in the size of plants. Some of these sunflower strains, however, although becoming extremely uniform, retained their former vigour, indicating that it is possible to retain a large number of desirable factors in an inbred strain.

In a later report McRostie (13) stated that after five generations of inbreeding, the sunflower lines were comparatively pure and the various strains showed striking differences in their reaction to climatic conditions and disease producing organisms. Some of these inbred lines showed a marked resistance to sunflower rust, *Puccinia helianthi*, Schw.

Platchek (14) also found that individual sunflower plants differed one from another in their immunity to attacks by various diseases and insects. He built up strains by straight selection which were highly immune to injury from Broom-rape, *Orobanche cumana*, Wallr. When plants from these strains were crossed with susceptible ones, the F_1 progeny was almost perfectly immune to this disease. The immunity appeared to be due to the nature of the pericarp.

Arnoldova (2) reported the results of a detailed study of the successive development of the different parts of the flower with special reference to its significance for artificial pollination. A method of crossing sunflowers is described which allows one person to emasculate 8 or 9 plants (about 1000 flowers) per hour. An experiment was also reported which showed that sunflower pollen stored for one year in paper packets at ordinary room temperatures was almost as viable as fresh pollen. This prolonged vitality of pollen affords a great opportunity to make crosses between plants which differ considerably in their time of blooming.

Platchek (15) described direct and reciprocal crosses between *Helianthus annuus* L., (edible form) and *Helianthus cucumerifolius*, Torr et Gray. The F_1 of the direct cross showed complete dominance of the *H. annuus* characters, but in the reciprocal cross some characters exhibited complete, and others partial, dominance. In the second generation segregation did not give a regular Mendelian ratio, but many interesting types evolved.

Cockerell (4) found that the primrose rayed varieties were recessive to the ordinary orange rayed types. The "coronatus" (red on ray petals) character also is a typical Mendelian dominant. A type of sunflower is described in which the ray flowers are missing, and crossing experiments seemed to indicate that this condition depended on several factors.

In further studies Cockerell (5) described a red rayed variety and offered some suggestions as to the cause of this pigmentation. He postu-

lates the operation of a factor inhibiting yellow, the loss of a dioxidizing factor, and the presence of a dilution factor, as possible explanations.

Cockerell (6) also crossed red rayed sunflowers with several yellow rayed species. The hybrids from one of these crosses carried red only on the tips of the ray petals. A group of hybrids from other species carried the red only on the base of the petals, whereas those from a third species showed red only on the centre portion of the petals. It is evident that sunflowers possess colour patterns, although these are generally masked.

Crosses were made by Cockerell (7) between different species and varieties of *Helianthus* to determine their fertility. The results showed that the progeny from these crosses were not as a rule very fertile—and would be useful only for ornamental purposes.

In another experiment Cockerell (8) demonstrated that when several different species were crossed the progenies varied considerably. He claimed that it is quite possible that these crosses occur naturally and that a botanical study of the genus *Helianthus* should make allowance for these hybrids.

Watson (20) published a key and description of 108 species of *Helianthus*. Great variations were found to occur within these species and the author explained that this unstable condition was due at least in part to the morphological response to edaphic conditions.

A statistical study was made by Reed (16) to determine if short sunflowers are shorter than average height all through their growth period, or whether they merely mature more rapidly. The experiment showed that the plants which were short in the seedling stage remained below average all through their development up to maturity. It was therefore assumed that the relative height of sunflower plants is dependent upon internal genetic factors rather than upon external casual ones.

Thorner (18) reports yields of from 800 to 1000 pounds of sunflower seed per acre grown under field conditions in the State of Washington. Only single types proved to be useful for seed production, and rigid selection was necessary as otherwise the multiple plants soon became numerous.

LOCATION AND PLAN OF EXPERIMENT

The area selected for this test was located on the Central Experimental Farm, Ottawa. The soil was a good clay loam, well drained, and reasonably uniform. The plots were fertilized a few days previous to seeding, a 4-8-4 fertilizer being applied at the rate of 720 pounds per acre. Eighteen strains of sunflowers were studied in the experiment, each of which had been inbred for at least 8 generations, thus being extremely uniform.

A fourfold replication of each strain was sown, and controlled randomization was resorted to in order to offset the effects of shading. The lines were therefore divided into 3 groups—tall, medium and short, and randomized within each group. The rows were 36 inches apart and the seed was sown by hand at 18-inch intervals, one row constituting a plot. Sowing was done on May 18, 1937, which is a later date than is usually the case in this district. This delay was unavoidable as frequent showers prevented the necessary cultivation to prepare the seed bed for this crop.

The rows were 34 feet 6 inches long and thus 23 plants constituted a perfect stand and provided a sufficiently large population so that the end plants could be entirely disregarded. Guard rows of "Mennonite" variety were sown at both sides of the ranges in order to minimize the border effect.

CLIMATE

The data contained in Table I were furnished by the Dominion of Canada Meteorological Service from the Station at Ottawa. In addition to reporting the weather conditions for the period when the crop was actually growing, figures are also included for the month of April, as these had a direct bearing on soil conditions at the time when the crop was sown.

TABLE 1.—METEOROLOGICAL DATA

Month, 1937	Mean Temperature	Highest temperature	Lowest temperature	Total precipitation	Total hours of bright sunshine
	°F	°F	°F	Inches	Hours
April	40.9	68	19	2.63	185.9
May	56.3	89	31	2.22	212.2
June	64.7	84	46	3.64	273.5
July	69.6	93	49	3.99	299.8
August	70.7	92	48	3.52	260.3
September	57.3	90	34	3.54	171.0

METHOD

Ten plants in each replication were selected at random and numbered from 1 to 10. Careful records were kept on each of these marked plants. When the majority of the plants in any one replication were in bloom, one of the unmarked plants was picked at random and this plant was taken to be representative of that replication in regard to the leaf area and the number of leaves per plant. It was not possible to use the method of measuring leaf area as described by Kramer (11), as a photo-electric cell was not available. Watson (19) outlined a method and presented mathematical formulae whereby leaf areas might be calculated from the weight of the fresh green leaves. In order to apply this method it is first necessary to obtain the mean weight per leaf by large sampling which was not possible in this experiment. The manner in which the leaf area per plant was calculated in this case was by stripping the leaves one at a time from the plant and tracing their outlines on brown paper. The paper replicas of the leaves were cut out and weighed, as was also a section of the paper with a known area of one hundred square inches. The weight of the leaves was then converted into area by simple proportion. A hundred square inch portion of paper was obtained as a check for each and every plant, but the paper was so uniform that the greatest difference between the weight of any two of these sections was less than one-fifth of one per cent. The date upon which the main head of each marked plant opened was recorded. When the seed in the main heads of any replication was in the dough stage the following notes were taken for each marked plant in that row: diameter

of the main head, height of plant, number of branches per plant, number of heads per plant. Immediately following this notetaking the heads were all covered by Manila bags to ensure against loss of grain by the birds or by shattering. When the heads were fully ripened they were harvested and transported to a barn where they were threshed out by hand rubbing. The seed from each plant was then placed in a tray and set in a drying rack. After two weeks of air drying the seed was cleaned in a small Clipper machine and weighed to one-tenth of a gram on agate-bearing trip scales.

After the weights had been recorded, the seed from every marked plant in a replication was bulked together and sent to the grain laboratory where it was tested to determine the percentage of oil in the whole seed. One variety gave insufficient seed for an oil test, and in another variety one of the four replications gave insufficient seed for the test. In the latter case the missing result was filled by using Allen and Wishart's (1) method.

The procedure for determining the oil percentage is as follows. The sunflower seed is finely ground on a Hobart burr mill, using the closest possible setting which will permit a free running meal. The ground material is then thoroughly mixed and dried in a DeKhotinsky Vacuum Oven for 18 hours at 98°–100° C. Five grams of the dried material are extracted on an electrically heated water bath for 16 hours with Skellysolve F (a low boiling petroleum ether) in a Soxhlet extractor, using Whatman double thickness extraction thimbles and a siphoning rate of one per minute. The ether extract is carefully transferred to a tared 125 cc. Erlenmeyer flask by suction, the extraction flask being washed with fresh solvent. The excess ether is distilled off on a water bath maintained at approximately 70°–80° C., the extract dried *in vacuo* for approximately two hours at 98°–100° C. at a pressure not exceeding 25 m. mercury and the oil content computed on a dry matter basis.

RESULTS

TABLE 2.—COEFFICIENTS OF TOTAL CORRELATION OBTAINED BETWEEN THE PERCENTAGE OF OIL IN THE SEED AND THE VARIOUS FACTORS STUDIED

Factors	<i>r</i>
Per cent oil <i>vs.</i> Area of leaves	— .017
Per cent oil <i>vs.</i> Number of leaves	— .159
Per cent oil <i>vs.</i> Diameter of main heads	.001
Per cent oil <i>vs.</i> Height of plants	.448
Per cent oil <i>vs.</i> Number of branches	— .109
Per cent oil <i>vs.</i> Number of days from seeding to blooming	.224
Per cent oil <i>vs.</i> Number of heads	.103
Per cent oil <i>vs.</i> yield of seed	.320

Correlation coefficient necessary for significance $P0.05 = 0.241$ ($P0.01 = 0.313$)

Number of degrees of freedom = 65.

TABLE 3.—COEFFICIENTS OF TOTAL CORRELATION BETWEEN THE YIELD OF SEED AND THE VARIOUS FACTORS STUDIED

Factors	<i>r</i>
Yield of seed <i>vs.</i> Area of leaves	.100
Yield of seed <i>vs.</i> Number of leaves	-.483
Yield of seed <i>vs.</i> Diameter of main heads	.127
Yield of seed <i>vs.</i> Height of plants	.476
Yield of seed <i>vs.</i> Number of branches	-.709
Yield of seed <i>vs.</i> Number of days from seeding to blooming	-.317
Yield of Seed <i>vs.</i> Number of heads	-.615

Correlation coefficient necessary for significance $P0.05 = .232$ ($P0.01 = 0.302$)
 Number of degrees of freedom = 70

DISCUSSION

Factors Affecting the Oil Percentage

A considerable amount of time, material and laboratory equipment is necessary if every strain in a large sunflower nursery must be tested to determine the amount of oil in the seed of that strain. Should a correlation exist between some morphological factor and the ability to produce seed high in oil content, it would then be possible to eliminate at least the poorest lines without actual testing, and thus cut down the amount of laboratory work considerably. With this object in mind, several coefficients of total correlation were obtained and have been presented in Table 2.

The results of this study showed that there was evidently no correlation between the oil percentage of the seed and the area of the leaves, the number of leaves, the diameter of the main heads, the number of branches, the number of days from seeding to blooming, or the number of heads per plant.

It would appear from Table 2, however, that the taller plants produced seed which was rich in oil as there was a highly significant positive correlation between the amount of oil in the seed and the height per plant. As pointed out by Goulden (9), it is quite possible that this correlation, although statistically highly significant, may not prove to be of practical significance. The reason for this supposition is that some third causal factor, such as the greater opportunity afforded the taller plants to utilize sunlight, may also influence this apparent relationship between the height of plants and the percentage of oil. It would therefore seem that although this presented evidence is impressive from the statistical standpoint, it should be further substantiated before being applied to actual plant breeding practices.

A highly significant positive correlation was obtained between the percentage of oil in the seed and the yield of seed. As the oil content was based on the analysis of the whole seed, and not on the kernels alone, it is logical to expect a higher yield of oil from the heavy, plump seed which would probably have a higher ratio of kernel to hull. This correlation would be affected by environmental conditions and, as it is based on only one year's results, cannot be regarded as being conclusive.

Factors Affecting Yield of Seed

A group of coefficients of total correlation involving yield of seed as the dependent variable were presented in Table 3. The object of this study was to determine whether or not it is possible to identify high yielding strains of sunflowers by observation in the field.

From the results presented in Table 3, it would appear that the area of the leaf surface of any line had no direct bearing on the yield of seed.

A very significant negative correlation was found to exist between the number of leaves and the yield of grain. It is not probable that a large number of leaves were actually detrimental to the seed bearing qualities of the plant, but rather that the varieties which had many leaves were generally of the branching multiple headed type which yielded poorly.

Contrary to general belief, there appeared to be no significant correlation between the yield of seed and the diameter of the main heads. The weight of seed produced in a head depends not only on the diameter of the head but also on the number of flower zones which are fertile and on the length of the kernels.

It may be observed in Table 3 that a very significant positive correlation exists between the yield of seed and the height of plants. An examination of the varieties in this test shows that most of the high yielding varieties were tall and, as a rule, the poor yielders were short. It is questionable if this statistical result is sufficiently conclusive to be used as the sole basis for selecting breeding material.

A very strikingly significant negative correlation coefficient was obtained between the yield of seed and the number of branches. The analysis of variance showed that had all the varieties possessing a large number of branches been discarded as breeding material, very few good yielding strains would have been eliminated by the use of this method of selection.

There was found to be a highly significant negative correlation between the yield of seed and the number of days from seeding to blooming. Weather conditions would influence this factor very considerably and, as this test was conducted for only one season, this cannot be said to be conclusive evidence.

From Table 3, it may also be observed that there is a very significant negative correlation between the yield of seed and the number of heads. It was thought that this result might be influenced unduly by the fact that four single, high yielding varieties were included in this test. Another statistical method was applied, this time including all the fourteen multiple headed strains but no single variety. The result of this calculation was as follows: Correlation coefficient obtained = -0.402 , with necessary difference of $P\ 0.05 = 0.246$ and $P\ 0.01 = 0.342$. It is therefore obvious that even when the single headed varieties were excluded a highly significant negative correlation is obtained. This result conflicts with the statement, "Contrary to common belief the better multi-headed types give more grain than the single headed sorts" made by Hamilton (10). This author, however, was evidently basing his conclusions solely on observations, as his inference was not supported by any figures.

A study of sunflower yields in Washington State convinced Thornber (18) that single headed plants outyielded multiple ones, and that it was advisable to rogue out constantly all multiple headed plants when producing sunflower grain for seed purposes.

SUMMARY

A statistically significant positive correlation was found to exist between the percentage of oil in the seed and the height of the plants, and similarly between the percentage of oil and the yield of seed produced.

A very significant negative correlation between the yield of seed and the number of leaves was observed. A very significant positive correlation was noted between the yield of seed and the height of plants. It was also observed that highly significant negative correlations existed between the yield of seed and the factors for number of branches, number of days from seeding to blooming and number of heads.

It is concluded that in a sunflower breeding project which has for its aim the production of a high seed-yielding variety of high oil content, the taller non-branching types are worthy of special consideration as basic breeding material.

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THE INFLUENCE OF NITROGENOUS, PHOSPHATIC AND POTASSIC FERTILIZERS ON THE CHEMICAL COMPOSITION AND BLENDING VALUE OF WESTERN CANADIAN WHEAT¹

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INTRODUCTION

On the Canadian prairies, experiments with the application of artificial fertilizers to cereal crops by the broadcast method failed to produce sufficient response to justify the recommendation of fertilizer for general use. In 1928, extensive experiments were initiated in the three Prairie Provinces in which relatively small quantities of triple superphosphate and ammonium phosphate were drilled in just below the seed, a method of application which had proven successful in other countries. Marked increases in yield and earlier maturity resulted where sufficient moisture was available, and in recent years the use of these fertilizers by this method is becoming current agricultural practice.

In 1929, a 3-year co-operative fertilizer project covering the various grain-growing areas in Manitoba was begun, in which nitrogenous, phosphatic, and potassic fertilizers singly and in combination were drilled in below Reward wheat with the object of zoning the province in regard to fertilizer requirements. This experiment and the yield results obtained have been fully dealt with in a paper by Ellis (3). In view of the marked increases in yield reported, particularly for those treatments which included superphosphate, it seemed of interest to determine whether these increases were obtained at the expense of protein content which is an important index of wheat strength.

Ash determinations were also carried out on composites for each district in the 1929 and 1930 series; phosphorus was determined on the composite samples for the control plots and those treatments which included a phosphatic fertilizer. For the former year, experimental milling and baking tests were also conducted.

¹ The experiments here reported were conducted on samples supplied to the Department of Agricultural Chemistry, University of Manitoba, through the courtesy of the Soils Division, Department of Agronomy, and the Manitoba Wheat Pool. These samples originated from fertilizer trials conducted in 1929, 1930 and 1931 by the "Junior Co-operators" and financed by the Educational Department of the Manitoba Wheat Pool co-operating with the Soils Division, Department of Agronomy. Grateful acknowledgment is also made of the assistance and advice given by Dr. C. H. Goulden, Dominion Rust Research Laboratory, in connection with the statistical treatment of the data.

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EXPERIMENTAL METHODS

As the general plan of the experiment has been detailed by Ellis (3), it need only be referred to briefly here. Reward wheat from one source was supplied to various co-operators so selected as to represent the 9 agricultural districts of Manitoba. Replicate rod-row tests were conducted and the fertilizers, shown in Table 1, drilled in 1 inch below the seed. The heads from 4 rows for each treatment were forwarded to the Soils Division, Department of Agronomy, University of Manitoba, for threshing. After weighing and calculating the yields, the samples were submitted to the authors. In some cases, samples were analysed from farms which were excluded from the yield records because of excessively high experimental errors; on the other hand, insufficient wheat was available from some farms for laboratory study. Accordingly, the number of farms reported upon differs slightly from those listed by Ellis (3).

Portions of the cleaned samples were ground to a fine meal in a Lab-conco burr mill and placed in air-tight containers for nitrogen determinations. Nitrogen was determined on a 2-gram sample by the Kjeldal-Gunning-Arnold method as outlined by the American Association of Official Agricultural Chemists (2). In order that the results might be expressed on a uniform moisture basis, moisture tests were made by the Official A.O.A.C. vacuum oven method.

District composite samples were prepared for the 1929 and 1930 series respectively by bulking equal quantities of wheat representing the different treatments from all farms in each district, for the purpose of ash and phosphorus determinations and experimental milling and baking tests. Ash analyses were made on 5 grams of the finely-ground samples by ignition in platinum dishes at 550° C.

TABLE 1.—AMOUNTS OF FERTILIZER APPLIED⁽¹⁾

Kind of fertilizer	Designation	Rate per acre in pounds	Pounds of fertilizer ingredients per acre		
			N	P ₂ O ₅	K ₂ O
Ammonium sulphate	N	112½	22½	—	—
Sodium nitrate	—	150	22½	—	—
Triple superphosphate	P	75	—	33	—
Sulphate of potash	K	50	—	—	24
Ammonium sulphate and triple superphosphate	NP	112½ and 75 = 187½	22½	33	—
Ammonium sulphate and potassium sulphate	NK	112½ and 50 = 162½	22½	—	24
Triple superphosphate and potassium sulphate	PK	75 and 50 = 125	—	33	24
Ammonium sulphate, triple superphosphate and potassium sulphate	NPK	112½ and 75 and 50 = 237½	22½	33	24

¹ The amounts of fertilizer given per acre were the amounts actually used on an acre basis with the drill rows one foot apart.

In determining phosphorus, 5 grams of the finely-ground wheat were mixed with an equal weight of anhydrous magnesium nitrate and incinerated in platinum at 600° C. until free from carbon. The ash was digested in a 100-cc. beaker with 10 cc. concentrated HCl for 2 hours on a steam bath, 25 cc. distilled water added, and the digestion continued for a further 90 minutes. The contents of the beaker were then transferred to a 200-cc. volumetric flask, made up to volume, and phosphorus determined on a 10-cc. aliquot by the Fiske and Subbarow colorimetric Method as outlined by Mather (7).

The 1929 composites were milled to a 70% patent flour on an Allis-Chalmers experimental mill following the flow sheet published by Geddes (4). To secure an index of blending value, the resultant flours were each blended with 40% of an Ontario winter wheat flour of approximately 9% protein content and baked by a formula containing 0.001% potassium bromate, 3% Fleischmann's yeast, 2.5% sucrose, and 1% salt, using the procedure described by Geddes, Malloch and Larmour (6); this method is essentially similar to that of the American Association of Cereal Chemists as later outlined by Geddes (5). The baking tests and all analytical determinations, except moisture, were conducted in duplicate, and the mean results reported for each of the 9 agricultural districts described by Ellis (3). Protein data only are given for the treatment with sodium nitrate and these are considered separately.

RESULTS

Wheat Protein

The mean wheat protein values for each fertilizer treatment except sodium nitrate are recorded by agricultural districts in Table 2, together with the standard errors for the treatment means. Differences between treatments exceeding 3 times the corresponding standard errors may be regarded as significant. The individual results for each co-operator, all districts combined for each year, were submitted to a variance analysis in which the total variance was subdivided into that due to differences between treatments, between districts, between co-operators within districts, to the interaction "treatment $\times$ districts", and to error.

The greatest source of variability is due to the differences between districts, but in each year the difference between treatments is highly significant. Only in 1930 was the interaction "treatments $\times$ districts" statistically significant, which implies that, in the main, the fertilizers affected the wheat protein in a similar manner in all districts.

The effect of fertilizer treatment is best shown in Table 3, in which the district mean values for the 4 treatments containing nitrogen, phosphorus and potash respectively are compared with the corresponding means for the 4 treatments in which these fertilizing elements were omitted.

TABLE 2.—MEAN PROTEIN CONTENT OF WHEAT (13.5% MOISTURE BASIS)

District	Year	Number of farms	Fertilizer treatment												Standard error of treatments
			Control		N	P	K	NP	NK	PK	NPK	Mean			
			%	%	%	%	%	%	%	%	%	%			
1 Red River Valley	1929	12	14.6	15.3	14.7	14.6	15.1	15.2	14.7	14.9	14.9	14.9	14.9	0.12	
	1930	10	14.4	14.5	14.0	14.2	14.2	14.3	14.1	14.4	14.3	14.3	14.3	0.32	
	1931	5	17.0	16.9	17.0	16.5	16.8	17.0	17.0	16.7	16.9	16.7	16.9	0.19	
2 Assiniboine Delta	1929	10	15.4	15.6	15.5	15.4	15.6	15.6	15.2	15.6	15.6	15.6	15.5	0.15	
	1930	11	13.8	14.2	13.5	13.8	13.6	13.8	13.8	13.6	13.8	13.6	13.8	0.33	
	1931	4	16.2	16.6	16.3	16.2	16.2	16.2	16.0	16.2	16.0	16.2	16.2	0.19	
3 Riding Mountain Wash	1929	5	15.3	15.5	15.4	14.8	15.6	15.5	15.4	15.7	15.4	15.7	15.4	0.21	
	1930	3	14.0	14.2	13.4	13.4	13.9	14.2	13.8	14.3	14.3	13.9	13.9	0.31	
	1931	—	—	—	—	—	—	—	—	—	—	—	—	—	
4 Dauphin Area	1929	3	15.6	15.6	15.9	15.5	16.2	15.8	16.2	15.6	16.2	15.6	15.8	0.24	
	1930	3	14.2	14.2	14.1	14.3	14.3	14.7	14.2	14.2	14.2	14.3	14.3	0.23	
	1931	1	17.9	18.5	17.4	17.0	17.4	17.7	17.5	17.9	17.9	17.7	17.7	—	
5 Swan River Valley	1929	6	13.0	13.7	13.1	13.2	13.8	13.4	13.4	13.6	13.4	13.6	13.4	0.20	
	1930	3	12.4	13.1	12.3	12.7	12.1	12.5	12.0	11.7	12.3	12.3	12.3	0.31	
	1931	2	14.0	14.6	13.0	12.8	13.1	13.6	12.8	13.6	13.6	13.4	13.4	0.39	
6 Northern Drift	1929	19	14.6	15.0	14.5	14.8	15.1	14.8	14.8	14.9	14.8	14.9	14.8	0.09	
	1930	16	13.7	13.8	13.6	13.5	13.9	13.6	13.7	14.0	13.7	13.7	14.0	0.29	
	1931	7	16.1	16.2	15.7	16.1	16.1	16.1	16.0	15.9	16.0	16.0	16.0	0.19	
7 Central Drift	1929	15	15.5	16.0	15.7	15.7	16.0	15.7	15.8	16.0	15.8	16.0	15.8	0.09	
	1930	8	14.4	14.6	14.3	14.2	14.6	14.6	14.2	14.6	14.5	14.5	14.5	0.17	
	1931	4	17.6	17.4	17.3	17.1	17.4	17.3	17.3	17.4	17.4	17.4	17.4	0.12	
8 Southern Drift	1929	17	17.0	17.3	17.0	17.1	17.3	17.1	17.3	17.4	17.4	17.4	17.1	0.12	
	1930	20	14.8	15.2	14.9	15.0	15.2	15.3	14.8	14.8	14.8	15.0	15.0	0.10	
	1931	5	17.6	17.5	17.3	17.4	17.4	17.7	17.5	17.3	17.3	17.5	17.5	0.13	
9 Southwestern Area	1929	26	16.7	17.0	16.8	16.8	16.9	16.8	16.6	16.8	16.6	16.8	16.8	0.02	
	1930	26	15.6	16.0	15.6	15.7	15.8	15.5	15.5	15.9	15.8	15.8	15.8	0.07	
	1931	1	17.1	16.8	16.9	16.6	16.7	16.9	17.2	16.9	16.9	16.9	16.9	—	
All districts	1929	113	15.69	16.10	15.76	15.76	16.06	15.76	15.78	15.99	15.81	15.99	15.81	0.04	
	1930	100	14.56	14.84	14.42	14.53	14.53	14.42	14.62	14.61	14.62	14.61	14.61	0.04	
	1931	29	16.69	16.74	16.43	16.39	16.48	16.60	16.47	16.46	16.53	16.53	16.53	0.08	

TABLE 3.—EFFECT OF SINGLE ELEMENTS ON WHEAT PROTEIN CONTENT

District	Year	Mean protein content (13.5% moisture basis)									Stan- dard error of treat- ment means
		With N	With- out N	Differ- ence	With P	With- out P	Differ- ence	With K	With- out K	Differ- ence	
		%	%	%	%	%	%	%	%	%	%
1	1929	15.13	14.65	.48	14.84	14.94	-.10	14.86	14.92	-.06	.06
	1930	14.35	14.16	.19	14.16	14.36	-.20	14.25	14.26	-.01	.16
	1931	16.84	16.89	-.05	16.88	16.85	.03	16.80	16.94	-.14	.10
2	1929	15.60	15.38	.22	15.46	15.51	-.05	15.45	15.53	-.08	.07
	1930	13.80	13.72	.08	13.64	13.88	-.24	13.73	13.79	-.06	.16
	1931	16.23	16.18	.05	16.12	16.28	-.16	16.11	16.29	-.18	.09
3	1929	15.58	15.21	.37	15.52	15.27	.25	15.34	15.44	-.10	.11
	1930	14.13	13.64	.49	13.84	13.93	-.09	13.91	13.87	.04	.16
	1931	—	—	—	—	—	—	—	—	—	—
4	1929	15.79	15.79	.00	15.97	15.62	.35	15.78	15.80	-.02	.12
	1930	14.35	14.21	.14	14.18	14.37	-.19	14.36	14.20	.16	.11
	1931	17.88	17.45	.43	17.55	17.78	-.23	17.52	17.80	-.28	—
5	1929	13.69	13.17	.52	13.48	13.39	.09	13.48	13.39	.09	.10
	1930	12.32	12.34	-.02	12.00	12.66	-.66	12.21	12.45	-.24	.15
	1931	13.70	13.16	.54	13.11	13.75	-.64	13.19	13.68	-.49	.19
6	1929	15.02	14.66	.36	14.80	14.87	-.07	14.87	14.80	.07	.04
	1930	13.88	13.59	.29	13.74	13.73	.01	13.73	13.74	-.01	.15
	1931	16.06	15.99	.07	15.91	16.13	-.22	16.01	16.03	-.02	.09
7	1929	15.95	15.68	.27	15.86	15.78	.08	15.85	15.78	.07	.05
	1930	14.34	14.31	.03	14.44	14.52	-.08	14.48	14.49	-.01	.09
	1931	17.38	17.32	.06	17.36	17.34	.02	17.28	17.42	-.14	.06
8	1929	17.26	17.02	.24	17.16	17.12	.04	17.15	17.13	.02	.06
	1930	15.10	14.89	.21	14.91	15.08	-.17	14.97	15.02	-.05	.05
	1931	17.46	17.45	.01	17.38	17.54	-.16	17.49	17.42	.07	.07
9	1929	16.93	16.72	.21	16.78	16.87	-.09	16.79	16.86	-.07	.01
	1930	15.92	15.60	.32	15.67	15.84	-.17	15.76	15.76	.00	.04
	1931	16.82	16.95	-.13	16.92	16.85	.07	16.90	16.88	.02	—
All districts	1929	15.96	15.66	.30	15.81	15.81	.00	15.81	15.81	.00	.02
	1930	14.73	14.48	.25	14.53	14.69	-.16	14.60	14.62	-.02	.02
	1931	16.57	16.49	.08	16.46	16.60	-.14	16.48	16.58	-.10	.04

* Necessary difference for significance equals three times the standard error.

These show that of the 3 fertilizing elements, nitrogen had the greatest effect on wheat protein, significantly increasing it by 0.30% and 0.25% for all districts combined in 1929 and 1930 respectively. On the other hand, fertilization with phosphorus decreased the mean protein content by an average of 0.16% and 0.14% protein in 1930 and 1931 respectively. Potash was without any significant effect. It is interesting to note that in 1931 the increase due to nitrogen fertilization was only 0.08% protein, a value which is not statistically significant. Ellis (3) has shown the precipitation to be considerably below normal that year and it is well known that such conditions tend to result in wheat of high protein content; without nitrogenous fertilization the average protein content for all districts in 1931 was approximately 16.6% as compared with 16.0% in 1929 (also a rather dry year) and 14.7% in 1930, for which years the use of nitrogen increased the wheat protein values by 0.30% and 0.25% protein respectively. While there are inconsistencies in the data, there is some indication that when wheat is grown under environmental conditions favouring high protein, the use of nitrogenous fertilizers will not effect as great an increase. While phosphorus shows a depressing effect in 2 out of the 3 years, this only amounted to from 0.14% to 0.16% protein and is of little practical significance as compared with the relatively large increases in yield per acre reported by Ellis (3).

The mean wheat protein values for the plots treated with sodium nitrate, all districts combined, were 15.82%, 14.77% and 16.60% for 1929, 1930 and 1931 respectively; these are 0.28%, 0.07% and 0.14% protein lower than the corresponding values for the ammonium sulphate treatments. The difference of 0.07% protein for 1930 is not statistically significant.

Wheat Ash

The means for duplicate ash determinations on the district composites given in Table 4 were submitted to an analysis of variance which revealed that the differences due to treatments were significant for 1930 but not for the 1929 series. The significant difference in 1930 is due principally to the slightly lower ash content of plots fertilized with nitrogen either alone or combined with phosphatic or potassic fertilizer. For all districts combined, the decrease for the mean of all treatments containing nitrogen amounted to 0.07% ash. Phosphatic fertilizer had a similar but lesser effect, the mean decrease being 0.03% ash, while potash had a negligible effect.

Phosphorus Content

Only the district composites for the control and the treatments including phosphorus, 1929 and 1930 series, were analysed for phosphorus content. The results gave no evidence of any change in the phosphorus content of wheat through the application of fertilizers containing this element.

Blending Strength

As an index of blending strength, the mean loaf volumes for duplicate baking tests were determined on a flour blend comprising 40% Ontario winter wheat flour with 60% of a 70% patent flour milled from each district composite for 1929. A variance analysis of the data showed that the differences between treatments for all districts combined were not statistically significant.

TABLE 4.—ASH CONTENT OF WHEAT.* DISTRICT COMPOSITES, 1929 AND 1930.

District	Year	Con- trol	Fertilizer treatment							Mean
			N	P	K	NP	NK	PK	NPK	
			%	%	%	%	%	%	%	%
1. Red River Valley	1929	1.42	1.38	1.38	1.42	1.35	1.36	1.44	1.35	1.39
	1930	1.74	1.72	1.75	1.72	1.68	1.68	1.81	1.58	1.71
2. Assiniboine Delta	1929	1.52	1.54	1.56	1.56	1.52	1.50	1.50	1.36	1.51
	1930	1.75	1.58	1.72	1.70	1.60	1.67	1.68	1.60	1.66
3. Riding Mountain Wash	1929	1.22	1.22	1.31	1.28	1.27	1.18	1.23	1.19	1.24
	1930	1.63	1.60	1.72	1.73	1.48	1.52	1.62	1.47	1.60
4. Dauphin Area	1929	1.27	1.28	1.20	1.18	1.20	1.51	1.17	1.27	1.26
	1930	1.64	1.65	1.52	1.62	1.50	1.64	1.59	1.46	1.58
5. Swan River Valley	1929	1.57	1.46	1.55	1.47	1.48	1.47	1.50	1.49	1.50
	1930	1.69	1.69	1.79	1.71	1.59	1.69	1.70	1.60	1.68
6. Northern Drift	1929	1.43	1.39	1.39	1.40	1.39	1.36	1.41	1.37	1.39
	1930	1.55	1.54	1.61	1.54	1.54	1.55	1.66	1.55	1.57
7. Central Drift	1929	1.52	1.57	1.45	1.53	1.48	1.45	1.43	1.44	1.48
	1930	1.58	1.53	1.58	1.54	1.47	1.49	1.55	1.46	1.52
8. Southern Drift	1929	1.58	1.52	1.55	1.55	1.51	1.54	1.58	1.57	1.55
	1930	1.55	1.61	1.58	1.60	1.56	1.64	1.62	1.57	1.59
9. Southwestern Area	1929	1.44	1.42	1.44	1.44	1.38	1.43	1.40	1.40	1.42
	1930	1.61	1.56	1.58	1.58	1.54	1.58	1.61	1.53	1.57
All districts	1929	1.44	1.42	1.43	1.43	1.40	1.42	1.41	1.38	1.42
	1930	1.64	1.61	1.65	1.64	1.55	1.61	1.65	1.54	1.61

Standard error for treatment means—all districts combined

For 1929 = .014%

For 1930 = .012%

* Mean of duplicate determinations, expressed on a 13.5% moisture basis.

In view of the significant mean increase of 0.3% in wheat protein content for those plots to which ammonium sulphate was applied, a small but significant increase in loaf volume also would be anticipated. However, the increase in wheat protein is slight, and in studies conducted by Aitken and Geddes (1) subsequent to these tests, it has been found that diluting a series of strong flours with a weak one for the purpose of estimating relative blending strength decreases the differentiation in loaf volume. Moreover, at the time the fertilizer studies were conducted, it was not fully realized that, in testing experimentally milled flours for strength, it is necessary to take special precautions through the addition of diastatic or non-diastatic supplements to preclude yeast starvation. Had this series of samples been baked without blending and under conditions which ensured adequate gas production, it is entirely possible that the small but significant difference in protein content as a result of nitrogenous fertilization would have been reflected in a similar increase in loaf volume. The negative effect of fertilizers in wheat strength, indicated in this study, is best interpreted as indicating no deleterious effect.

DISCUSSION

The results of these fertilizer trials applied by the drilling-in method conform to those which have been the general experience for the older broadcast method. Application of inorganic nitrogenous fertilizers has usually resulted in somewhat higher wheat protein values, but the increase is not sufficient to justify their use from this standpoint alone. Experiments reported in the literature also show that phosphates applied in liberal amounts generally lower the protein content, while potash does not materially affect the composition of the grain.

Where actual deficiency in phosphorus and other inorganic elements exists, it has been found that the application of the deficient element results in a large increase in its percentage in the plant. The similarity in the phosphorus content of wheat from the control plots and those fertilized with phosphorus indicates that the soils on which these trials were conducted were not lacking in this nutrient. In fact, Ellis (3), in his paper covering the yield results for this project, shows that the soils were "potentially fertile".

The explanation of the increased yields which result over the cereal-producing areas of the prairies by drilling in small quantities of soluble phosphatic and nitrogenous fertilizers close to the seed appears to lie in a seasonal deficiency of available nitrogen and phosphorus. Chemical activity is reduced in the dry summers and autumns and is inhibited by frost during the long winters. At the time of seeding, the soil is still relatively cold and micro-biological activity is at a low ebb; as a consequence, the application of relatively small quantities of available nitrogen and phosphorus at this time has a pronounced effect on plant development, bringing about a more rapid growth and the development of a root and leaf system which makes more adequate use of the available nutrients liberated by increased biological activity as the soil temperature rises. The results of this study show that the increased yields with wheat are not obtained at the expense of quality.

SUMMARY

Reward wheat harvested from plots grown in 1929, 1930 and 1931, in which small quantities of nitrogenous, phosphatic and potassic fertilizers singly and in combination were drilled in with the seed in each of the 9 agricultural districts in Manitoba, has been submitted to chemical analysis and experimental milling and baking tests.

Of these 3 nutrients, nitrogen, applied as ammonium sulphate, had the greatest effect on wheat protein content. For all treatments containing this ingredient the mean increase for all agricultural districts was 0.30% and 0.25% protein in 1929 and 1930 respectively. In 1931, which was drier than normal, the general protein level was high, and nitrogenous fertilization had no significant effect.

In 1930 and 1931, phosphorus decreased the mean protein content by an average of 0.16% and 0.14% protein. Potash was without any significant effect in any year.

Fertilization with sodium nitrate gave lower mean wheat protein values than ammonium sulphate in 1929 and 1931, by 0.28% and 0.14% protein respectively.

Ash content of wheat was reduced through fertilization with ammonium sulphate (singly and in combination) by 0.07% ash in 1930; in this year the decrease due to triple superphosphate was 0.03% ash, while potash had no significant effect. In 1929, ash content was not influenced by fertilizer treatment. Ash was not determined on the 1931 series.

There is no evidence of any increase in the phosphorus content of wheat through the application of triple superphosphate singly or combined.

Fertilization had no significant influence on blending strength, as indicated by loaf volume, employing a blend-bromate baking formula.

The results of this study agree with the explanation that the increased yields obtained on the Canadian prairies by drilling in soluble nitrogenous and phosphatic fertilizers are due to a seasonal deficiency in available nutrients at the time of germination. The increased yields are not obtained at the expense of wheat quality.

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MALTING QUALITY OF CANADIAN BARLEYS

II. NINETEEN VARIETIES, 1936 AND 1937 TRIALS¹

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Since Part I (4) of this series of papers was published, malting tests have been made at the University of Manitoba on samples of barley grown in a number of field investigations undertaken for various purposes by several Canadian research workers. Nine of these investigations yielded data on the comparative malting qualities of 3 or more barley varieties, the total number of varieties studied in all 9 investigations being 19. Data on these varieties are now published in summary form in the belief that they will facilitate the work of plant breeders who are endeavouring to produce barley varieties of good malting quality which are better suited to Canadian conditions, and that they will also be of use to others who are interested in the growing, merchandizing, processing and consumption of malting barley.

In Canada the malting qualities of all varieties are compared with those of O.A.C. 21. This variety is specified as the standard of malting quality in the Canada Grain Act, and long experience has shown that it is satisfactory for the production of both brewers' and diastatic malts. It appears to possess all the desirable and essential morphological and biochemical properties, and produces grain of satisfactory malting quality over a comparatively wide range of environment. As a working hypothesis it has therefore been assumed that any variety which is closely similar to O.A.C. 21 in its barley and malt properties will prove acceptable to Canadian maltsters for the production of brewers' malt for domestic consumption, and to those British maltsters who use Canadian barley for the production of diastatic malts.

In considering the data presented in this paper it must be borne in mind that the procedure used for comparing varieties with the standard one is by no means perfect. All varieties do not fall in the same relative order with respect to any barley or malt property, when grown under different environments. It follows that in comparing varieties it would be best to grow them for a number of years at a very large number of stations so as to obtain a series of samples representing the full range of environments occurring in the barley growing areas of Canada. The comparative values of the varieties could then be judged on the basis of their average performance. Unfortunately it is difficult to adopt this ideal procedure. The co-operation of the agricultural experimental stations in Canada is readily obtained but there are relatively few of these, by comparison with the area of Canada, and they are not distributed in the best malting barley

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areas. Attempts to obtain additional samples by getting farmers to grow them in properly replicated and randomized plots have been fairly successful, but the amount of administrative work and supervision required is large and not so readily available. The problem of obtaining a reasonable sample of seasons, by carrying on investigations for a number of years, presents no additional difficulties, but precludes the rapid accumulation of a really reliable body of data on new varieties. This last limitation can be overcome in part by testing varieties in both Eastern and Western Canada, since a wide range of environment can thus be obtained across Canada within one season.

In view of these difficulties, and because of the limited capacity of the malting laboratory, it has frequently been possible to test only small series of samples. However, by using statistical analyses it is possible to estimate whether the differences between varietal means can be considered significant, *i.e.*, whether they would persist if the means represented an infinite number of samples covering the full range of environment. Unfortunately the available statistical procedure is sound only if the small series of barley samples represent a random sample of environments. This they rarely do. The danger of obtaining a biased comparison of varieties therefore exists and must be kept in mind.

A second imperfection in the procedure arises from the fact that all samples are malted under a standard set of conditions. It follows that not all samples are malted to best advantage. This has been demonstrated by malting small series of samples under different conditions (2, 3, 7), and it has been found that when the malting conditions are changed the spreads between the mean values for certain pairs of varieties also change. It appears, however, that this differential effect of malting conditions on varieties, though an appreciable source of error, is not large in comparison with the differences between varieties of good and poor malting quality. In these circumstances it seems safe to assume that the routine malting test, involving the use of a standard set of malting conditions which simulate those used in commercial practice in Canada serves adequately for the separation of varieties which differ fairly widely with respect to any important property.

One further limitation must also be kept in mind. The malting test compares samples with respect to certain readily measured properties but fails to elucidate many other important ones. This defect results partly from limitations of time and staff, and partly because practicable methods for the routine determination of certain important properties have not yet been developed. The small number of properties now studied necessitates conservative interpretation of malting data. If tests show that a variety is seriously lacking in any important property it seems safe to assume that it is inferior in malting quality. On the other hand, if a variety is shown to be equal to the standard with respect to all properties measured, it cannot be unconditionally assumed that it is equal in quality, for malting purposes, to the standard, since it may be lacking in some quality not measured in the test. The authors believe, however, that the experimental maltster and analyst, in working with the malts, or through consideration of the intra-varietal relations between the properties studied, will generally find clues to any hidden deficiencies, and that these could be brought to light by more intensive study of the variety.

In view of these limitations it is apparent that the routine malting test can serve only for the preliminary separation of varieties into those which are about equal to O.A.C. 21 and those which are definitely inferior to it with respect to at least one important property. Those varieties which pass the routine examination may require further investigation, involving tests under a range of malting conditions and the study of a larger number of malt properties, before they can be classed as equal in malting quality to O.A.C. 21. Experience leads us to believe that comparatively few varieties will merit additional study. In order to do so it will be necessary for them not only to show promise in the routine test, but also to be generally more satisfactory, from the agronomic viewpoint, than O.A.C. 21 and other varieties now admitted to the malting grade, or at least to be better suited agronomically to some particular area.

The various considerations discussed in the preceding paragraphs should be kept in mind in reading the remainder of this paper in which the results of routine malting tests made on 516 samples of barley, representing 19 varieties, are presented and discussed.

MATERIALS

The barley samples were collected from 9 investigations, all of which were undertaken with the primary object of studying the agronomic characteristics and behaviour of different varieties under various environmental conditions. Owing to the limited capacity of the malting laboratory and the necessity for making other types of studies, it was impossible to test all samples from all 9 investigations. A number of varieties and stations were therefore chosen from each investigation and malting tests were made on samples representing these only.

The investigation number, the year in which it was made, the total numbers of varieties and stations in the investigation, and the numbers of varieties and stations from which samples were selected for malting, are listed in the first 6 columns of Table 1. The names of the stations from which samples were collected are given in column 7. The numbers occurring after the western stations enables their positions to be located by reference to the map (Figure 1). The map does not show the 11 stations in Eastern Canada included in investigations numbers 6 and 8.

The last 2 columns of Table 2 give the names of those under whose direction the investigations were carried out, and of the companies or institutions which financed them. This information is given partly in order to list those to whom the authors are indebted for growing and collecting samples, and partly because the information gives some idea of the scope and co-operative nature of the investigations of barley varieties now in progress in Canada under the direction of the National Barley Committee and its various sub-committees.

Essentially the same field plan, with minor and unimportant variations, was used in each investigation. The barleys were grown in plots of 5 rod-rows, arranged in a balanced block or random block, with quadruplicate plots for each variety. Marginal effects were minimized by harvesting only the centre 3 rows. The samples for malting were obtained by bulking the grain harvested from quadruplicate plots, and submitting to the laboratory an aliquot part weighing about 1200 gm.

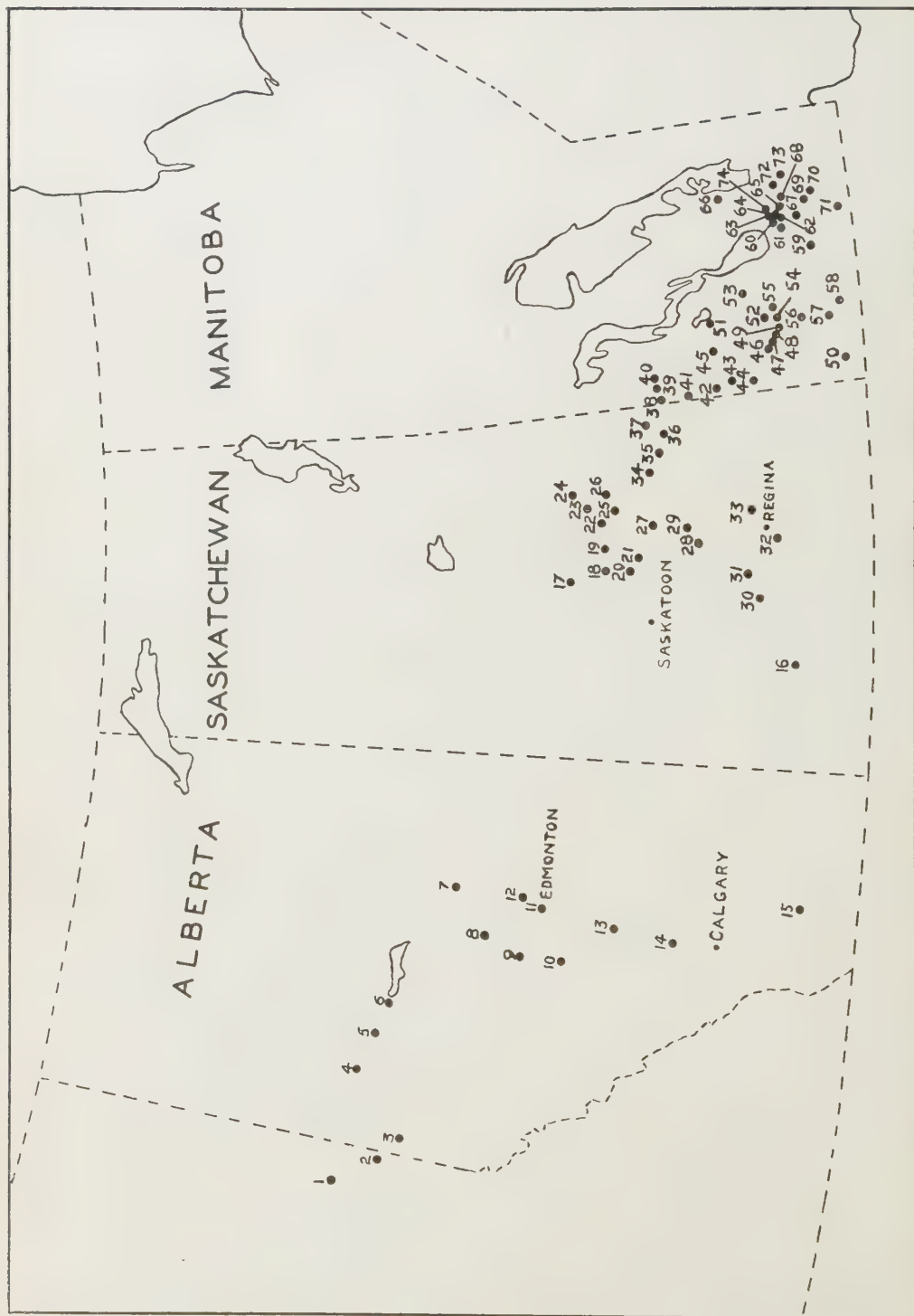


Figure 1. Map of Prairie Provinces of Canada showing locations of stations at which samples of barley were grown. The key to the names is given in the seventh column of Table 1.

TABLE 1.—DESCRIPTION OF INVESTIGATIONS

Investigation No.	Year	Total No. in investigations		No. selected for malting		Stations selected (See Figure 1)	Under the direction of	Financed by
		Varieties	Stations	Varieties	Stations			
1	1936	24	23	7	6	Beaverlodge, Alta. 3; Brandon, Man. 56; Edmonton, Alta. 11; Gilbert Plains, Man. 45; Melfort, Sask. 19; Ste. Anne de la Pocatière, Que.	Mr. P. R. Cowan, Central Experimental Farm, Ottawa.	Dominion Dept. of Agriculture, culture.
2	1936	10	7	6	6	Athabasca, 7; Beaverlodge, 3; Bon Accord, 12; Falis, 9; Mellowdale, 8; and Warburg, 10; all in Alberta.	Dr. K. W. Neatby, Univ. of Alberta, Edmonton.	United Grain Growers of Alberta.
3	1936	9	77	3	32	Arbore, 66; Benito, 48; Boissevain, 50; Clunwilliam, 52; Dauphin, 51; Dropmore, 42; Digald, 73; Elie, 63; Fannystelle, 67; Fortin, 62; Gilbert Plains, 45; Gordon, 72; Graysville, 57; High Bluff, 62; Ipswich, 47; Macaroff, 41; Marquette, 65; Miltonas, 40; Moorepark, 54; Newdale, 49; Norgate, 53; Oakville, 64; Osborne, 69; Otterburn, 70; Portage la Prairie, 60; Rackham, 71; Roblin, 43; Shool Lake, 46; Solsgirth, 44; Strathclair, 48; Swan River, 39; and Thornhill, 71; all in Manitoba.	Mr. D. M. McLean, Provincial Dept. of Agriculture, Winnipeg, Man.	Manitoba Pool Elevators, Ltd.
4	1936	6	300	5	22	Anahim, 21; Arnley, 25; Birch Hills, 18; Bjorkdale, 26; Danwell, 36; Gowan, 38; Grand Coulee, 32; Invermay, 35; Kelvington, 34; Leacross, 23; Melfort, 19; Middle Lake, 20; Neville, 16; Norquay, 37; Paddockwood, 17; Qu'Appelle, 33; Raymore, 29; Rowletta, 30; Star City, 22; Tugaskie, 31; Watson, 27; and White Fox, 24; all in Saskatchewan.	Dr. J. B. Harrington, Univ. of Saskatchewan, Saskatoon.	Saskatchewan Co-operative Wheat Producers, Ltd.
5	1937	24	23	12	12	Beaverlodge, Alta. 3; Brandon, Man. 56; Fredericton, N.B.; Gilbert Plains, Man. 45; Guelph, Ont.; Lacombe, Alta. 13; Lethbridge, Alta. 15; Nappan, N.S.; Ottawa, Ont.; Ste. Anne de Bellevue, Que.; Ste. Anne de la Pocatière, Que.; Winnipeg, Man.	Mr. P. R. Cowan, Central Experimental Farm, Ottawa.	Dominion Dept. of Agriculture, culture.
6	1937	8	6	6	6	Beaverlodge, 3; Dreau, 5; Fairview, 4; and High Prairie, 6; in Alberta; Baldonnet, 1; and Pouce Coupe, 2; in British Columbia. All in the Peace River District.	Mr. W. D. Albright, Dom. Exp. Sta., Beaverlodge.	Dominion Dept. of Agriculture, culture.
7	1937	8	8	6	6	Beaverlodge, 3; Bon Accord, 12; Falis, 9; Mellowdale, 8; Olds, 14; and Warburg, 10; all in Alberta.	Dr. K. W. Neatby, Univ. of Alberta, Edmonton.	United Grain Growers of Alberta.
8	1937	12	6	4	6	Kemptville, Kinburn, Lochiel, Napan, Ottawa, and Westboro; all in the Ottawa Valley, Ontario.	Mr. P. R. Cowan, Central Experimental Farm, Ottawa.	Dominion Dept. of Agriculture, culture.
9	1937	9	41	4	9	Elie, 63; High Bluff, 62; Holland, 59; Killarney, 58; Marquette, 65; Moorepark, 54; Neepawa, 55; Rackham, 74; and Thornhill, 71; all in Manitoba.	Mr. D. M. McLean, Provincial Dept. of Agriculture, Winnipeg, Man.	Manitoba Pool Elevators, Ltd.

TABLE 2.—MALT, MALTING, AND BARLEY PROPERTIES OF O.A.C. 21, MEAN VALUES FOR EACH OF NINE INVESTIGATIONS

Investigation No.	Number of samples	Malt			Malting		Barley		
		Extract, %	Diastatic activity, °L.	Perm. sol. wort nitrogen, % wort solids	Loss, %	Sprouts, %	Total nitrogen, %	1000-kernel wt., gm.	Plump barley, %
1	6	73.5	145	1.14	8.0	2.4	2.39	30.2	69
2	6	73.3	116	—	7.6	1.8	2.31	32.7	83
3	32	71.9	165	—	9.9	2.8	2.45	—	55
4	22	73.1	138	—	8.0	2.4	2.39	—	75
5	12	73.9	127	1.10	7.4	2.2	2.24	31.0	74
6	6	73.6	111	0.93	8.1	2.6	2.24	—	83
7	6	72.6	152	1.27	8.4	2.7	2.60	—	93
8	6	74.5	141	1.30	8.2	2.5	2.36	—	67
9	9	73.4	143	1.17	9.2	2.9	2.30	29.7	56
Weighted mean	105	73.0	144	1.15*	8.6	2.5	2.38	30.8*	68

* Calculated from results for less than 105 samples.

METHODS

Malting

Before malting, each sample was split into two subsamples by means of a Boerner sampler and the thin barley was removed by passing each sub-sample over a ring grader, with rings $\frac{5}{16}$ inch apart, driven at constant speed by means of a reducing gear and electric motor. The amount of barley recovered was recorded and is reported as "Plump barley, %."

An aliquot part of each sub-sample, representing 250 gm. of barley dry matter, was then malted in the laboratory equipment, and under the malting conditions previously described (5). In making the malts precautions were taken to obtain as unbiased a comparison of the varieties as possible. To this end sub-samples of all varieties from 1 station were malted in the same batch, and duplicate malts were generally made in different batches. The positions of the sub-samples within batches and the allocation of stations to batches were randomized within each investigation. Malting loss and percentage sprouts (roots) were determined immediately after kilning. The sample was weighed and then kneaded for 1 minute in a small bag. The roots which were rubbed off by this process were removed by sifting and the finished malt was weighed. The percentage malting loss is calculated from data on the weight and moisture content of the finished malt and the weight and moisture content of the sample used for malting. The figures reported for sprouts are rather low since some of these are rubbed off and lost during the kilning process.

Analytical

Total nitrogen content and 1000-kernel weight of the barley were determined in duplicate on the cleaned (plump) sample,⁵ the former by the Kjeldahl method, and the latter by weighing out duplicate samples of

⁵ Determinations of nitrogen for investigations 2 and 4, and of 1000-kernel weight for investigations 2, 3 and 4, were made prior to cleaning by the men who submitted the samples.

25 gm. and counting the number of kernels in each. For most of the investigations these determinations were made either by the investigator who submitted samples or at the Central Experimental Farm, Ottawa.

Extract and moisture content of the malt; odour of mash; colour, appearance, and speed of filtration of the wort; and conversion time; were determined by the official methods of the American Society of Brewing Chemists (1). Diastatic activity was determined by a ferricyanide modification of the official method (6), and permanently soluble wort nitrogen was determined by a method previously described (2).

RESULTS

A total of 516 samples of barley and duplicate malts made from these were examined in the investigations described in this paper. Three determinations were made in duplicate on most of the barley samples and 14 determinations were made on each malt. The study thus yields a total of over 17,000 data. It is apparent that space limitations prohibit publication of all these. Moreover, the authors consider that no useful purpose would be served by so doing. Masses of original data are comparatively unenlightening until they have been analysed, suitably summarized, and interpreted. This is a task of no mean proportions and one which forms an integral part of research of no less importance than the proper collection of data.

This paper is designed to present information on the comparative malting qualities of the barley varieties studied, and the data have been summarized from this viewpoint only. The investigations also provided information on the effect of environment on malting quality and the differential effect of environment on varieties, but no attempt is made to discuss these subjects or to present data bearing on them, in this paper.

Significant varietal differences were not demonstrated with respect to 5 minor determinations. We may therefore dispose of these by listing them together with the mean values for them: moisture content of malt, 3.3%; odour of mash, "very aromatic"; time of conversion, less than 5 min.; speed of filtration, "normal"; colour of wort, 1.6 Lovibond units.

The data yielded little evidence of varietal differences in wort clarity. Worts from all samples of all varieties except 2 were classed as "clear". The 6 samples of Trebi, which was grown only in the Peace River Investigation (No. 6), yielded cloudy worts. Three of the 58 samples of Regal also gave cloudy worts, and these 3 samples were also grown in the Peace River District. It seems probable that environmental effects were at least partly responsible for the cloudiness of worts from these samples.

Significant varietal differences were demonstrated with respect to malt extract, diastatic activity of malt, wort nitrogen, malting loss, percentage sprouts, total barley nitrogen, 1000-kernel weight of barley, and percentage plump barley. The mean values for the standard variety O.A.C. 21, for each of these 8 determinations and for each investigation, are listed in Table 2. Data for the remaining 18 varieties are summarized in Table 3. Each figure represents the difference between the mean value

Other rough-awned 6-rowed	Pontiac	5	12	-1.3*	4	-0.05*	-0.5*	-0.2*	0.04	1.3	5*
Smooth-awned 6-rowed	Trebi	6	6	-4.0*	-29*	-0.27*	-2.5*	-1.0*	-0.09	—	8*
	Newal	6	6	-2.5*	44*	-0.03	-1.3*	-1.0*	0.19*	—	10*
		7	6	-1.2*	39*	0.03	1.6*	-0.8*	0.12	—	3
	Nobarb	1	6	-1.1	-28*	-0.18*	-1.2*	-0.7*	0.01	2.7*	11*
		5	12	-1.0*	-27*	-0.21*	-1.0*	-0.6*	-0.05	2.7*	6*
	Regal	1	6	-1.9*	-49*	-0.07	-0.7*	-0.3*	0.06	0.8	2
		2	6	-2.8*	-38*	—	-1.2*	-0.4*	0.08	0.9	1
		4	22	-2.0*	-50*	—	-0.7*	-0.6*	0.06	—	0
		5	12	-2.7*	-41*	-0.06*	-0.4*	-0.5*	0.11*	0.5	2
		6	6	-5.0*	-45*	-0.13*	-2.0*	-0.8*	0.09*	—	5*
2-rowed		7	6	-4.4*	-49*	-0.06	-1.3*	-0.9*	0.18*	—	4
	Velvet	1	6	-2.3*	-7	0.02	-0.7*	-0.3	0.27	-0.6	2
		5	12	-1.6*	-3	0	-0.8*	-0.5*	0.13	0.1	2
	Wisconsin 38	5	12	-2.7*	-31*	-0.20*	-0.8*	-0.6*	0	1.3	12*
	Hannchen	4	8	0.9	-12*	—	-0.9*	-0.6*	0.15*	—	3
		5	12	3.0*	-11*	-0.07*	-0.3	-0.3*	-0.02	4.6*	9*
	Charlottetown 80	5	12	2.2*	-27*	-0.11*	0.2	-0.1	0.06	4.0*	8*
	Victory	5	12	2.0*	-24*	-0.18*	-0.3	-0.1	-0.01	5.0*	10*
	Rex (smooth-awned)	1	6	-0.1	0	0.10	-0.6*	-0.5*	0.27*	6.4*	8

* Values significant.

TABLE 4.—COMPARATIVE MALT, MALTING AND BARLEY PROPERTIES OF VARIETIES, DIFFERENCES BETWEEN WEIGHTED MEAN FOR EACH VARIETY AND CORRESPONDING WEIGHTED MEAN FOR O.A.C. 21

Class	Variety	Investigation No.	Number of samples	Malt			Malting		Barley		
				Extract, %	Diastatic activity, °L.	Perm. sol. nitrogen, % wort solids	Loss, %	Sprouts, %	Total nitrogen, %	1000-kernel wt., gm.	Plump barley, %
"Standard"	O.A.C. 21, Mean	1-9	105	73.0	144	1.15	8.6	2.6	2.38†	30.8	66
	Cartons	3, 9	41	-1.0*	7*	0.05	-0.8*	-0.7*	0.36*	0.8	0
	Mensury	3	32	0.3	7*	—	-0.3*	-0.2*	0.01	—	1
	Mensury, Ott. 60	5, 8, 9	27	-0.1	4	0	-0.1	0	0.04	0.8	3
	Peatland	1, 2, 4-9	59	-1.3*	2	0.01	-0.2*	-0.3*	0.32*	-2.7*	-13*
Other rough-awned, 6-rowed	Brio	2, 7	12	2.2*	-22*	-0.01	-0.3	-0.5*	-0.14*	-3.1*	0
	Lapland	2	6	3.4*	13*	—	0.6*	0.1	-0.17*	-5.2*	-18*
	Olli	1, 2, 4-8	48	2.0*	23*	0.11*	0.4*	0	-0.01	-2.2*	-8*
	Pontiac	5	12	-1.3*	4	-0.05	-0.5*	-0.2*	0.04	1.3	5
	Trebi	6	6	-4.0*	-29*	-0.27*	-2.5*	-1.0*	-0.09	—	8*
Smooth awned 6-rowed	Newal	6, 7	12	-1.8*	42*	-0.03	-1.4*	-0.9*	0.16*	—	6*
	Nobarb	1, 5	18	-1.0*	-27*	-0.20*	-1.1*	-0.6*	-0.03	2.7*	8*
	Regal	1, 2, 4-7	58	-2.8*	-46*	-0.08*	-0.9*	0	0.09*	0.7	0
	Velvet	1, 5	18	-1.8*	-4	-0.01	-0.8*	-0.4*	0.18*	-0.1	2
	Wisconsin 38	5	12	-2.7*	-31*	-0.20*	-0.8*	-0.6*	0	1.3	12*
2-rowed	Hannchen	4, 5	20	2.3*	-11*	-0.07*	-0.5*	-0.4*	0.05	4.6*	7
	Charlottetown 80	5	12	2.2*	-27*	-0.11*	0.2	-0.1	0.06	4.0*	8*
	Victory	5	12	2.0*	-24*	-0.18*	-0.3	-0.1	-0.01	5.0*	10*
	Rex (Smooth Awn)	1	6	-0.1	0	0.10*	-0.6*	-0.5*	0.27*	6.4*	8*

* Values significant.

† Mean values for commercial samples of No. 3 Extra Canada Western barley are somewhat lower, viz.,—1934, 2.07%; 1935, 2.22%; 1936, 2.29%; 1937, 2.29%; and 1938, 2.21%.

for the variety in question, in a single investigation, and the corresponding mean value for O.A.C. 21 (see Table 2). Positive numbers thus indicate that the value for the variety in question was greater than that for the standard variety, and negative numbers that it was less.

Differences between O.A.C. 21 and any other variety are considered significant when statistical analyses show that the odds are 19 to 1, or greater, that these are caused by real differences between the varieties. Data representing significant differences are marked with an asterisk. It must be borne in mind that the magnitude of the difference necessary for significance tends to decrease as increasing numbers of samples are studied. In consequence, necessary differences are not the same for all investigations.

Table 4 presents a further summary of the data given in Tables 2 and 3. Weighted means for each variety, over all investigations in which it was included, were calculated and the corresponding weighted means for O.A.C. 21 were subtracted from these. Thus Table 4 presents, by means of one line of data for each variety, the essential information required for the discussion of the malting qualities of each variety as compared with those of O.A.C. 21.

DISCUSSION

The authors believe that in order to be considered promising from the malting viewpoint, a variety should be not lower than O.A.C. 21 in extract yield, diastatic activity and percentage permanently soluble wort nitrogen (cf. 8; 9, Ch. V; 10, p. 156). Since only that part of the malt which can be extracted is used in the brewing and allied malt-consuming industries, it is obvious that a higher extract yield than that given by the standard is advantageous. On the other hand, higher diastatic activities are advantageous only for the production of diastatic malts. It seems doubtful whether a higher percentage of wort nitrogen than that given by O.A.C. 21 can be considered advantageous and there is even some possibility that very high values may prove undesirable from the brewing viewpoint.

In our opinion a variety should also yield values for malting loss and percentage sprouts not lower than those for the standard. Low values indicate slow growth, probably resulting from enzyme deficiencies, and suggest that the variety will not modify readily within the 6-day germination used in this country.

It is important that the average nitrogen content of a variety should not exceed that of O.A.C. 21 (cf. 10, p. 160). Any tendency towards high nitrogen content will reduce the area over which a variety will produce grain of satisfactory malting quality. Moreover, we believe that high average nitrogen content, unless accompanied by correspondingly high enzymatic activity, will generally result in less ready modification during malting. For this reason it is frequently illuminating to compare the malt properties of varieties at equal nitrogen contents. The process is possible since intra-varietal correlations exist between barley nitrogen, on the one hand, and diastatic activity, wort nitrogen and extract, on the other hand: on the average, diastatic activity increases by 6° Lintner, wort nitrogen increases by 0.04%, and extract decreases by 0.45%, for each 0.1% increase in total nitrogen.

A high percentage of plump barley (*i.e.*, of barley suitable for malting) is certainly advantageous and, other things being equal, high 1000-kernel weight is also desirable. It should be borne in mind, however, that adequate modification within 6 days is more readily attained with short kernels, so that high 1000-kernel weight may actually be disadvantageous if it results from extra length rather than greater plumpness.

The data given in Table 4 show that among the rough-awned 6-rowed varieties now admitted to the malting grades, Mensury and the selection made from it, Mensury Ott. 60, must be considered equal in quality to O.A.C. 21 with respect to all properties measured. Gartons and Peatland have two defects in common, they tend to be high in nitrogen content and low in extract yield. Though both appear to be equal to O.A.C. 21 in percentage wort nitrogen this must be attributed partly to their high total nitrogen contents, and if comparisons were made at equal nitrogen contents both varieties would be lower than the standard in wort nitrogen. We are inclined to believe that these two varieties may be somewhat deficient in proteolytic and other enzymes, a hypothesis which is supported to some extent by the low values they give for malting loss and percentage sprouts. Peatland also suffers from an additional defect, since it tends to produce grain of low 1000-kernel weight and grain containing a low percentage of plump barley. Since 41 samples of Gartons and 59 samples of Peatland have been studied it now seems justifiable to draw rather definite conclusions about the malting quality of these two varieties. Because of their slightly lower extract yields and higher nitrogen contents we class them as somewhat inferior in malting quality to O.A.C. 21.

Amongst the other rough-awned 6-rowed varieties, Olli, of which we have studied 48 samples, appears definitely promising. It is high in extract yield and enzymatic activity, grows readily, and has about the same average nitrogen content as O.A.C. 21. On the other hand it is low in 1000-kernel weight and percentage of plump barley. We believe, however, that its deficiencies are offset by its high extract yield and that it will prove satisfactory for the production of both brewers' and diastatic malts. Lapland is very similar to Olli but is extremely low in 1000-kernel weight and percentage plump barley. It does not appear promising, but since only 6 samples of it have been examined some additional study may be advisable. Further investigation of Brio and Pontiac might show that these should be classed as only slightly inferior in malting quality to O.A.C. 21. The former is high in extract yield but low in diastatic activity, whereas the latter is low in extract yield. There is thus no reason to suppose that either will prove to be superior to O.A.C. 21 in general malting quality. The inferiority of Trebi for malting purposes has been so firmly established by commercial maltsters that it seemed unnecessary to undertake extensive laboratory study of it. The data given in Table 4 show its deficiencies. It should be borne in mind, however, that the 6 samples studied were grown in the Peace River District and were not fully mature, so that the data probably give an exaggerated picture of the faults of the variety.

All of the 5 smooth-awned 6-rowed varieties studied are characterized by slow growth and low extract yield. Nobarb, Regal and Wisconsin 38 also give very low values for diastatic activity and wort nitrogen, and must accordingly be classed as definitely inferior in malting quality to O.A.C. 21.

Except for the fact that Newal has an extraordinarily high diastatic activity, it and Velvet have much the same characteristics. They both grow slowly, and are high in nitrogen content and low in extract yield. Both would be about 1% lower in extract yield than O.A.C. 21 even if comparisons were made at equal nitrogen content. Thus, though Velvet and Newal appear to be the best of the smooth-awned varieties studied, they must be classed as somewhat inferior in malting quality to O.A.C. 21.

Data on the 3 rough-awned, 2-rowed varieties, Hannchen, Charlotte-town 80 and Victory, are only of theoretical interest since practical experience has demonstrated that varieties of this class do not modify adequately within 6 days when grown under environments, such as occur in the large barley growing areas of Canada, which tend to produce grain of comparatively high nitrogen content. It seems probable that satisfactory malt cannot be made from 2-rowed barleys of higher nitrogen content than 1.8%, and there is therefore little demand in Canada for malting barleys of this class. The 3 varieties mentioned above show the usual characteristics of their class, high 1000-kernel weight, high extract, and rather low enzymatic activity, the last factor being indicative of less ready modification. It is interesting to note that Hannchen, which is malted to some extent in the United States, is more similar in malt properties to O.A.C. 21 than the other 2 varieties.

The smooth-awned 2-rowed variety, Rex, yields anomalous results. It was produced from a cross between a 2-rowed and a 6-rowed parent. It has the high 1000-kernel weight of the former and the malt properties of the latter. The fact that its larger kernels do not yield the expected extract yield suggests some serious deficiency in malting quality. This does not, at first sight, appear to be associated with lack of enzymatic activity. However, if the variety's very high nitrogen is taken into account, it appears that there is some slight deficiency in this respect. In other words, if Rex were compared with O.A.C. 21 at equal nitrogen contents, it would appear higher in extract but lower in diastatic activity and percentage wort nitrogen. Definite conclusions with respect to the malting quality of this variety can hardly be drawn from the results of a study of only 6 samples, but because of its high nitrogen content and because of its 2-rowed characteristics it seems safe to say that it does not appear promising from the malting viewpoint.

It seems advisable to point out that the authors see little reason for believing that plant breeders cannot produce a smooth-awned variety of satisfactory malting quality. Data given in Table 4 show that Nobarb is no higher than O.A.C. 21 in nitrogen content. Moreover, it is only 1% lower in extract, and this deficiency results largely from the fact that only a relatively small percentage of its nitrogen is made soluble in the wort. On the other hand, though there are indications that a low percentage of wort nitrogen is a characteristic of the smooth-awned varieties, both Newal and Velvet give percentages of wort nitrogen which are considerably higher than that for Nobarb. Moreover, it will be noted that Velvet is about equal to O.A.C. 21 in diastatic activity, whereas Newal is phenomenally high in this respect. If a smooth-awned variety could be developed which would have the satisfactory barley properties of Nobarb, the proteolytic activity of Velvet, and some of the diastatic activity of

Newal, it would probably be equal to O.A.C. 21 in extract yield and might well prove very satisfactory for malting purposes. It appears that the generally unsatisfactory malting qualities of the group of smooth-awned varieties now grown in Canada is a heritage from the original smooth-awned parent, Lion. There is little reason for believing, however, that deficiency with respect to any individual malt property is linked so closely with the smooth-awned character that a smooth-awned variety cannot be developed without a deficiency. It thus appears that it should be possible to breed out the inherent malting deficiencies of this class of barleys whilst maintaining the smooth-awned characteristic which the farmer finds attractive.

SUMMARY

It is pointed out that the procedure for comparing the malting qualities of varieties by means of the routine malting test is subject to limitations arising from the differential effect of environment on varieties, the differential effect of malting method on varieties, and the relatively small number of barley and malt properties studied. The routine test serves only for the elimination of varieties which show marked deficiencies with respect to one or more important barley or malt properties. Other varieties may require further study before they can be classed as fully equal in malting quality to the standard variety, O.A.C. 21.

A summary is presented of the results obtained by comparing from 6 to 59 samples, grown under different environmental conditions, of each of 18 varieties, with corresponding samples of O.A.C. 21. Varietal differences were found with respect to extract yield, diastatic activity, and percentage permanently soluble nitrogen of the malt; malting loss and sprouts; and with respect to total nitrogen content and 1000-kernel weight of the barley, and percentage of plump barley.

Mensury and Mensury Ott. 60 are considered fully equal in quality to O.A.C. 21 with respect to all properties measured. Olli yields higher values for malt properties but this advantage is partially offset by low 1000-kernel weight and percentage plump barley. Gartons, Peatland, Newal and Velvet should be considered somewhat inferior to the standard because of high nitrogen content and low extract yield. Brio, though high in extract, is low in diastatic activity; Pontiac is low in extract; and Lapland, though similar to Olli in other respects, is very low in 1000-kernel weight and percentage plump barley; these three varieties are not considered promising. Trebi, Nobarb, Regal and Wisconsin 38 exhibit deficiencies with respect to all malt properties studied. Data on the 2-rowed varieties, Hannchen, Charlottetown 80, Victory and Rex, are presented, but it is pointed out that 2-rowed varieties do not modify as readily as 6-rowed varieties, and that the demand for the former class of barley for malting in Canada is almost negligible.

Although none of the 5 smooth-awned 6-rowed varieties studied proved satisfactory, the authors see little reason for believing that a smooth-awned variety of satisfactory malting quality cannot be developed.

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